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NATO Reference Mobility Model (NRMM) Modeling of the DEMO III Experimental Unmanned, Ground Vehicle (XUV)

by Timothy T. Vong, Gary A. Haas, and Caledonia L. Henry

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Aberdeen Proving Ground, MD 21005-5066

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Weapons and Materials Research Directorate, ARL

Abstract

The Advanced Weapons Concepts Branch, Army Research Laboratory (ARL), was asked to assess and evaluate the predicted cross-country performance of the current DEMO III Experimental Unmanned Ground Vehicle (XUV) chassis design using the NATO Reference Mobility Model (NRMM) by the Program Manager of the Department of Defense sponsored DEMO III XUV Program. The XUV modeled approximately 2,500 lb that will be able to traverse cross-country terrain at 20 mph. The XUV is designed to be driven by an autonomous mobility package, but the NRMM does not support autonomous mobility; so, for the purposes of this study, the chassis was modeled as a manned vehicle. Currently, the XUV is in the final chassis and suspension development phase by the systems integrator, Robotic Systems Technology, Inc. The NRMM is a computer-based simulation tool that can predict a vehicle's steady-state operating capability (effective maximum speed) over specified terrain. The NRMM can perform on-road and cross-country prediction of a vehicle's effective maximum speed. The NRMM is a matured technology that was developed and proven by the Waterways Experiment Station (WES) and the Tank-automotive and Armaments Command (TACOM) over several decades. The NRMM has been revised and updated throughout the years; the current version used to perform this analysis is version 2, also known as NRMM II. ARL was also asked to compare the predicted performance of the XW chassis against the high-mobility, multipurpose, wheeled vehicle (HMMWV) using NRMM II. This report details the NRMM II analysis and assessment of the DEMO III XUV and WES HMMWV.

Acknowledgments

The authors would like to thank those who provided valuable information and/or help. They are:

- Richard B. Ahlvin, U.S. Army Waterways Experiment Station (WES)
- Bailey T. Haug, U.S. Army Research Laboratory (ARL)
- Jeffrey S. Robertson, Robotic Systems Technology, Inc. (RST)
- Bradley Beeson, Robotic Systems Technology, Inc. (RST)

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1. Introduction

This report details the NATO Reference Mobility Model (NRMM) analysis and performance assessment of the DEMO III Experimental Unmanned Ground Vehicle (XUV) and a high-mobility, multipurpose, wheeled vehicle (HMMWV), and the comparison of their predicted performance. The XUV modeled, shown in a conceptual rendering in Figure 1, is a semi-autonomous unmanned ground vehicle (UGV) weighing approximately 2,500 lb. The assessment and evaluation results may influence design changes in the XUV. This report is being provided to the system's integrator and the DEMO III community to allow the participants to gauge the predicted performance of the currently designed DEMO III XUV.

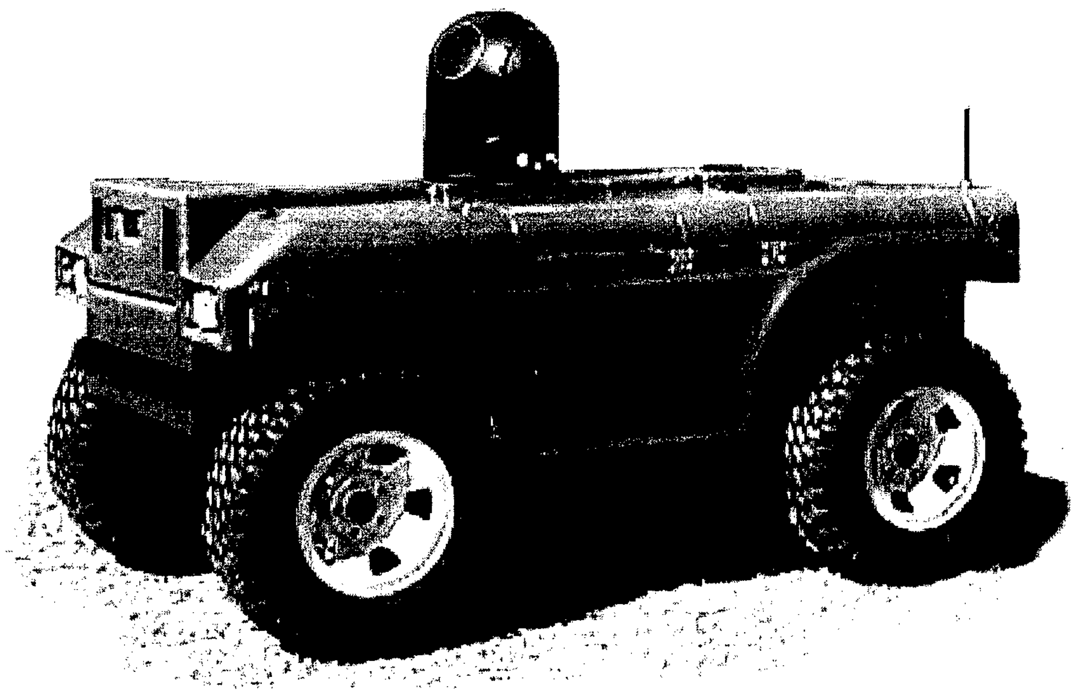


Figure 1. Conceptual Rendering of DEMO III XUV

The Advanced Weapons Concepts Branch (AWCB), U.S. Army Research Laboratory (ARL), was requested to perform the NRMM analysis of the DEMO III XUV by the Program Manager (PM) of the Department of Defense (DOD) sponsored DEMO III XUV program. The goal of DEMO III is to develop an XUV that can maneuver on the battlefield at the tactical speeds of manned platforms. The HMMWV was selected as the basis for comparison of the XUV's ability to keep pace on the battlefield. The main objectives in the modeling effort were to predict: (1) the mobility of the currently designed XUV chassis in cross-country terrain, (2) XUV mobility performance compared to the current HMMWV in cross-country terrain, and (3) the ability of the XUV chassis to meet the required DEMO III exit criteria to traverse cross-country terrain at 20 mph. This criteria has been interpreted by the DEMO III community to mean that a HMMWV can traverse at 25 to 30 mph. The system's integrator, Robotic Systems Technology, Inc. (RST), is currently in the final chassis and suspension development phase for the XUV. AWCB was asked to assess and evaluate the cross-country performance of the current DEMO III XUV design using NRMM. The HMMWV modeled was the M 1025, armament carrier version. The U.S. Army Waterways Experiment Station (WES), the developer of the NRMM, provided the model of the HMMWV.

The NRMM is a computer-based simulation tool that is widely accepted in the mobility community as a means to predict a vehicle's steady-state operating capability (effective maximum speed) over specified terrain. The NRMM can perform predictions of a vehicle's effective maximum speed on-road and cross-country. The NRMM is a mature technology that was developed and proven by the WES and the U.S. Army Tank-automotive and Armaments Command (TACOM) over several decades. The NRMM has been revised and updated throughout the years; the current version that was used to perform this analysis is version 2, also known as NRMM II.

The NRMM is divided into three separate primary modules: (1) a vehicle dynamics module (VEHDYN II), (2) an obstacle-crossing performance module (OBS78B), and (3) a primary prediction module (NRMM Main). These three program codes are run independently. The VEHDYN II and obstacle-crossing programs process generic obstacle and terrain data sets that produce vehicle specific results that become inputs for the main predicting module's vehicle data. During processing, the main module accesses these data to obtain a prediction appropriate for the specific terrain being processed [1]. This report details the work involved within each module and the results relative to the DEMO III XUV. The WES HMMWV results used for the comparison in the VEHDYN II and obstacle-crossing modules were obtained from WES. The WES HMMWV NRMM Main input file is listed in Appendix A.

The mobility predictions presented in this paper are intended to facilitate comparison between the vehicle designs, not to predict actual vehicle performance. NRMM predictions explicitly assume the frailties of a human driver and implicitly assume the capabilities of a human driver. While the XUV is designed as an unmanned vehicle, there has been no attempt to compensate the NRMM mobility performance predictions for this difference. Therefore, the predictions for the XUV may differ substantially from what is achieved by the actual vehicle for reasons associated with its unmanned nature, not from its chassis design.

2. VEHDYN II Module

The VEHDYN was originally developed in 1974 in support of the Army Mobility Model (AMM). In 1978, the AMM and its supporting VEHDYN were adopted as the standard references for evaluating the cross-country mobility performance of vehicles by a NATO working group. The AMM was subsequently renamed the NRMM. The adoption of NRMM and VEHDYN as NATO standards brought about widespread use and modifications. Unfortunately, this caused numerous inconsistencies, programming errors, redundant variables, and an unwieldy program. In 1986, to remedy this situation, the VEHDYN was rewritten to include many of the changes and renamed VEHDYN II [2].

The VEHDYN II is a two-dimensional (2-D) vehicle dynamics model. As shown in Figure 2, the user provides a vehicle description set, terrain and geometry set, and threshold limits. The vehicle description is specific to the studied vehicle. The terrain, geometry, and threshold limits used are VEHDYN II standards that are provided and known. The terrain (surface roughness) units are measured in root mean-square (RMS) values varying from O-6 ins RMS. The geometries are half-rounds measuring from O-l 8 inch. Once all the proper input parameters are given, the program is executed and the output is obtained using 6 W and 2.5 g's (gravity) as threshold values. These threshold values are steady-state tolerance levels of human drivers derived from years of experimental testing by WES and TACOM to validate the NRMM.

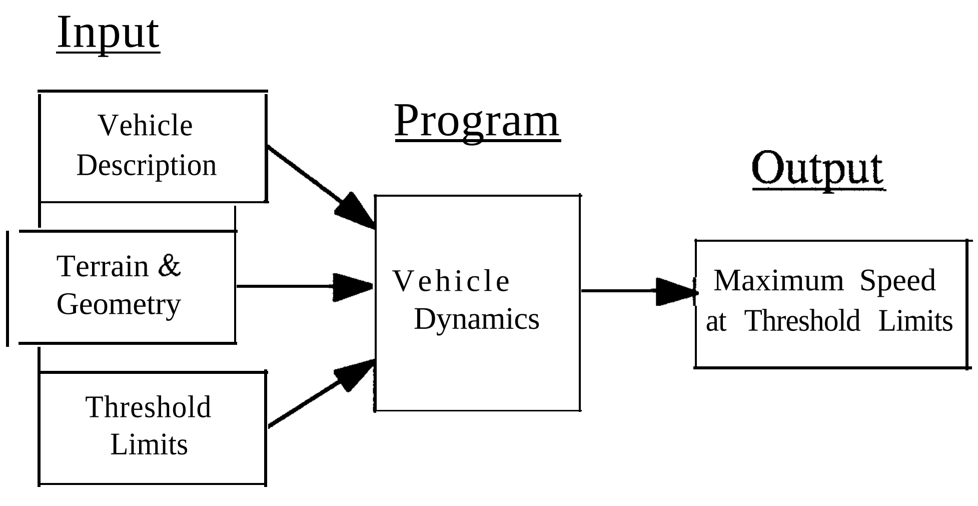


Figure 2. VEHDYN II Module Schematic

The final output from VEHDYN II is two resultant graphs. One graph is the maximum speed vs. surface roughness (inches RMS), the other is maximum speed vs. half-rounds (inches). Further explanation of VEHDYN II can be obtained from the users manual [2].

2.1 Input Data

The XUV is refered to as XUV3 in this report to match the configuration control of the DEMO III effort. The majority of the XUV3 vehicle input data is obtained from RST suspension design data, revision 3, dated 7/98. The vehicle specifications obtained from RST are the spring data, shock data, various vehicle dimensions, and weight characteristics. The tire data were derived from ARL and Aberdeen Testing Center (ATC) testing. Test data were obtained for numerous operating pressures of the tire. All other parameters in the input data file were derived from hand calculations using various formulas, most using the previously mentioned parameters as input. The actual VEHDYN II input files are found in Appendix B. The VEHDYN II users manual gives a more detailed description of the data files and its input parameters, if the reader is interested.

2.2 Results

Figures 3 and 4 are the compiled dynamic results of VEHDYN IT for the XUV3 vs. the WES HMMWV. The results are evaluated at the thresholds of 6 W for the terrain and 2.5 g's for the half-round bumps.

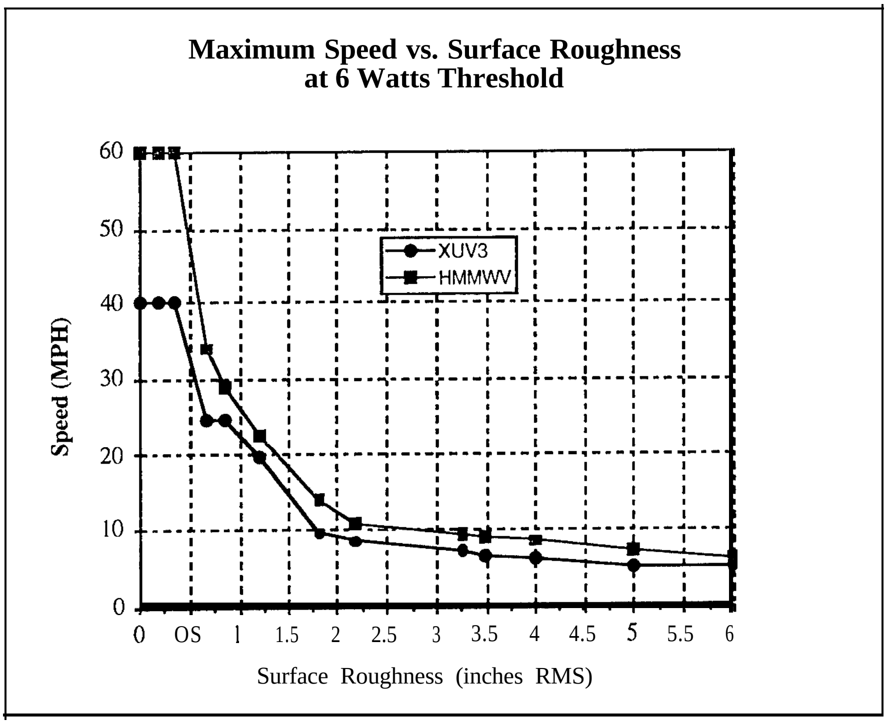


Figure 3. XUV3 and WES HMMWV Dynamic Terrain Results

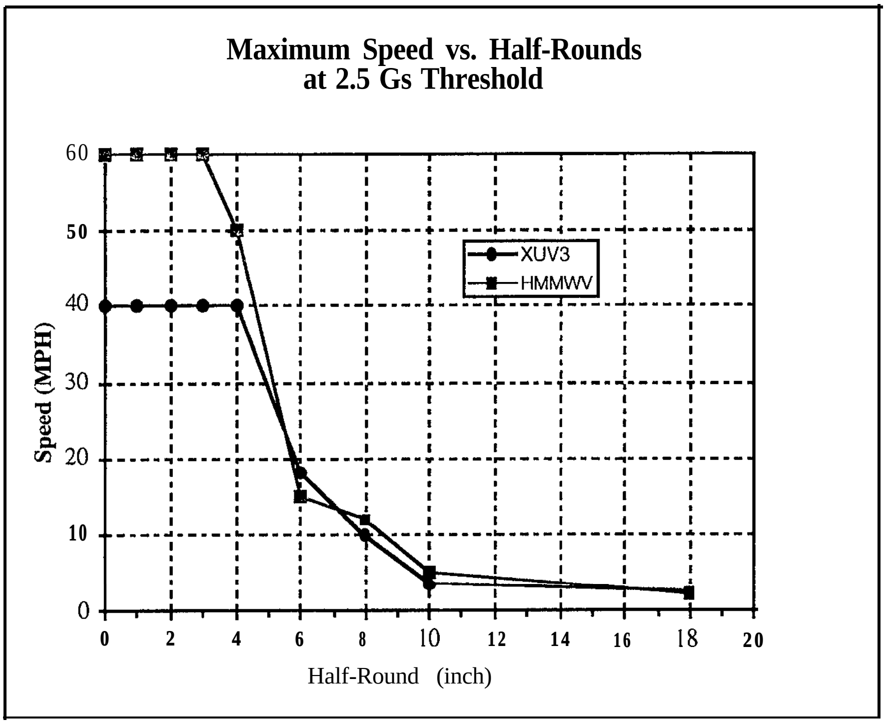


Figure 4. XUV3 and WES HMMWV Dynamic Geometry Results

2.3 Discussions

From the vehicle dynamics aspects and using the stated threshold values, the DEMO III XUV performs similar to the HMMWV. For most of the terrains and bumps, they are only separated by a few miles per hour. They are separated by larger margins for values of terrain and bump height, where each vehicle is limited by its maximum speed ability. The XUV3, with its current drivetrain configuration, has a calculated maximum speed of 40 mph, The HMMWV is limited to 60 mph. Although the true HMMWV maximum speed might be greater than 60 mph, for the purposes of our analysis, it was capped at 60 mph since maximum HMMWV speed was not our focus. From the curves, if the maximum speed is either 40 or 60 mph, it means their maximum speeds are not limited by the 6 W or 2.5 g's threshold but by factors not modeled. In order for the XUV3 to meet the DEMO III performance goals, it has to be able to traverse cross-country terrain at 20 mph. One suggested interpretation of this criterion is that the XUV3 traverse terrain at 20 mph that a manned HMMWV traverses at 25 to 30 mph. From Figure 3, this corresponds to terrain with a surface roughness of approximately 1.0 in RMS. On terrain of this sort, the VEHDYN II model predicts that the XUV3 is ride-quality limited at 23 mph.

3. Obstacle-Crossing Module

The obstacle-crossing module is a 2-D program that calculates a vehicle's ability to cross an obstacle set. Its output to NRMM Main, summarized in Figure 5, is the minimum clearance (or maximun interference) and the maximun propulsive force needed to override the obstacles in the set specific to each vehicle.

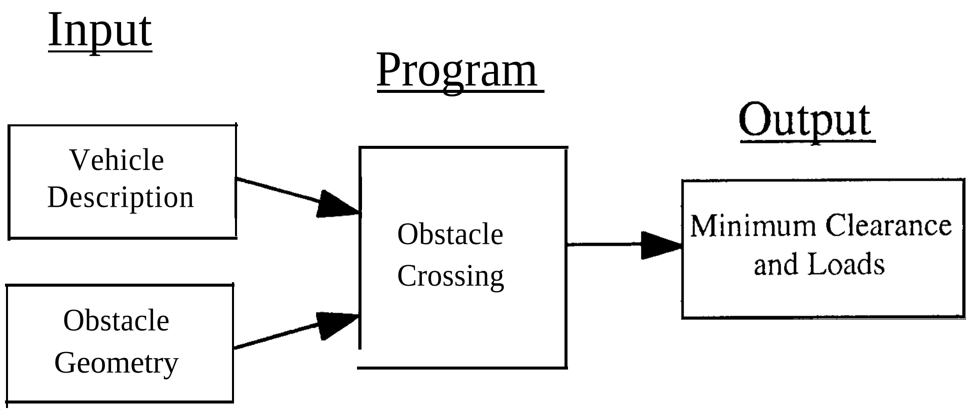


Figure 5. Obstacle-Crossing Module Schematic

These obstacle geometries are standard trapezoidal shapes, shown in Figure 6. The obstacle set for a wheeled vehicle is made up of combinations of three height levels, three width lengths and eight approach angles (122” to 248 °).

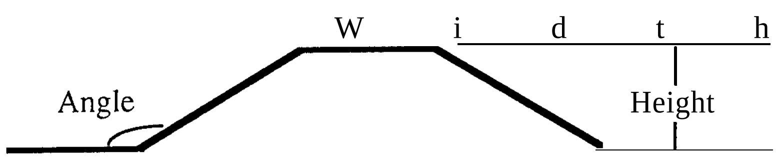


Figure 6. Diagram of Standard Trapezoidal Obstacle

Since the angles are greater and less than 180” (flat if 1 SO”), the obstacle set includes both positive and negative obstacles. More detail can be obtained from the users manual [3].

3.1 Input Data

The majority of the XUV3 vehicle input data for obstacle crossing like center of gravity, ground clearance profile, and vehicle front/rear weight distribution were obtained from the RST suspension design data, revision 3, dated 7/98. Other parameters not explicitly obtained from RST were derived from hand calculations of various formulas, using the RST parameters as input. The actual obstacle crossing input files are found in Appendix C. The obstacle crossing users manual [3] gives a more detailed description of the data files and input parameters, if the reader is interested.

3.2 Results

Figure 7 shows the total percentage of failures for the obstacle set by both the XUV3 and HMMWV. Failure is measured by a negative minimum clearance of vehicle while traversing a particular obstacle within the obstacle set. The color for “same obstacles” indicates the percentage of the same obstacles failed of the total set that both vehicles failed. The color for “different obstacles” indicates the percentage of the obstacles failed of the total set that each respective vehicle failed. The sum of different obstacle and same obstacle equals the total failure of each respective vehicle.

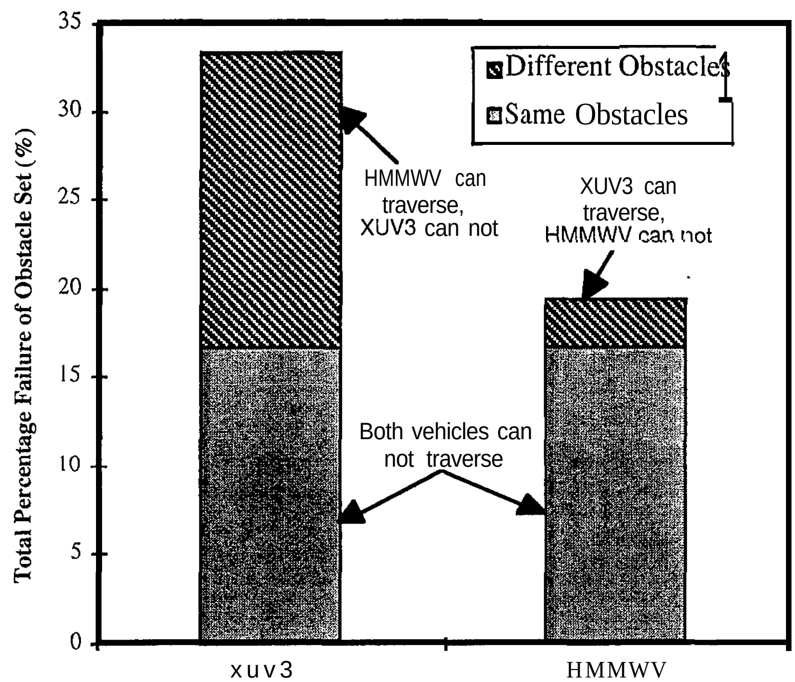


Figure 7. Obstacle-Crossing Failure Comparison of XUV3 and HMMWV

3.3 Discussion

The obstacle-crossing analysis indicates total failures of approximately 33% and 19% for the XUV3 and WES HMMWV, respectively. Of the total failures for both vehicles, approximately 17% were from the same obstacles within the obstacle set. In all, the XUV3 failed to traverse 14% more of the obstacle set than the HMMWV. These results are based on all the obstacles in the set. Since a subset of these obstacles is used in each theater scenario selected for the NRMM Main, the obstacle-crossing difference in the final analysis can vary from these results. The obstacle-crossing failures can be attributed to any of several vehicle characteristics like clearance height, wheel base, or front and rear overhangs affecting the angles of approach and departure.

4. NRMM Main Module

The primary output of the NRMM Main Module is the prediction of speed-made good of a given vehicle over specified terrain. Speed-made good is the effective maximum speed in the long run, and takes into account not only pure physical factors, such as powertrain capability, terrain grade, and traction available from soil of a specific type, but also subjective factors, such as driver tendency to slow down over uneven surfaces or in low visibility, A complete description is given in Ahlvin and Haley [1]. The NRMM is typically run over a collection of terrain units representative of an area of terrain, and the speed-made-good is represented as a profile of terrain area traversable at speed, ordered from highest speed to lowest. Another profile is the “accumulated” speed profile, which represents the average speed-made-good over the least difficult terrain.

Another perspective of interest is the particular factor limiting the speed of the vehicle over the terrain element. For off-road terrain, it is of particular interest which factor caused the vehicle to be unable to traverse a terrain unit, a condition known as “No-Go”. The NRMM calculates (accumulates) the proportion of the terrain where speed-made-good is limited by each of 13 factors, and the proportion of the terrain made untraversable by each of 9 factors. A block diagram description is shown in Figure 8.

In this study, the mobility of the XUV3 is compared to that of the HMMWV in two theaters under two weather conditions. Results are tabulated in a form that facilitates comparison of speed and accumulated-speed profiles, Go/No-Go statistics, and Go/No-Go factor statistics. This study was limited to comparison of pure vehicular mobility as predicted by the NRMM, which implicitly assumes the capabilities and explicitly allows for the vulnerabilities of a human driver. The study did not attempt to address differences in mobility resulting from the robotics nature of the XUV.

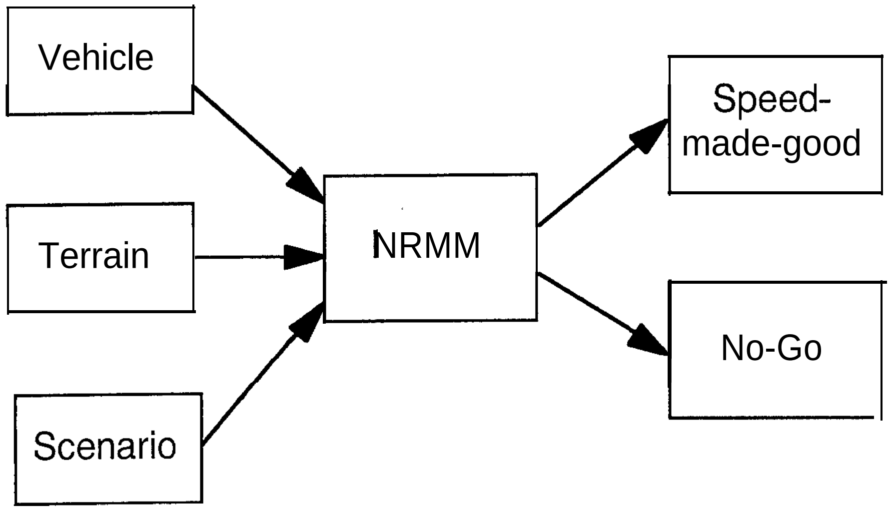


Figure 8. NRMM Main Module Schematic

4.1 Input

Vehicle data have a number of components, including vehicle geometry, mass distribution characteristics, tire characteristics, tractive force curve (the force that can be applied to the ground by the drivetrain, as a function of ground speed), threshold curves from the obstacle-crossing and ride-quality modules, braking performance information, and miscellany such as the height of the driver's eyes above the ground. The bulk of this information was provided by RST or derived by ARL from RST data. The source of individual data items is documented in line-by-line comments in Appendix A, section A.1. For the HMMWV, a vehicle description in NRMM format was provided by WES.

The terrain is described as a collection of homogeneous terrain elements statistically representative of the overall terrain. Each terrain element is described in terms of grade, soil type, seasonal surface strength, vegetation characteristics (stem size and density), seasonal visibility distance, surface roughness, and obstacle size and geometry (trenches and mounds). Terrain used for the comparison was NRMM terrain files representative of Europe and Southwest Asia. Data for these theaters is part of the NRMM package distributed by the NRMM program office.

Scenario data contains generic data that are independent of vehicle and terrain, such as weather conditions, vegetation override strategy, etc. For this study, the scenario was modified to evaluate both dry and wet/slippery conditions in each theater. (The wet/slippery condition represents standing water from a recent rain during an average wet season.) To avoid an unmanageable number of variables, all scenarios were run in October foliage conditions.

4.2 Results

Velocity profiles of the two vehicles over both theaters, and both wetness conditions were similar in that the XUV3 was several miles per hour slower over the entire terrain than was the HMMWV, and the HMMWV could traverse somewhat more terrain than could the XUV. A representative velocity profile is shown in Figure 9. Other profiles are in Appendix A, section A.6.

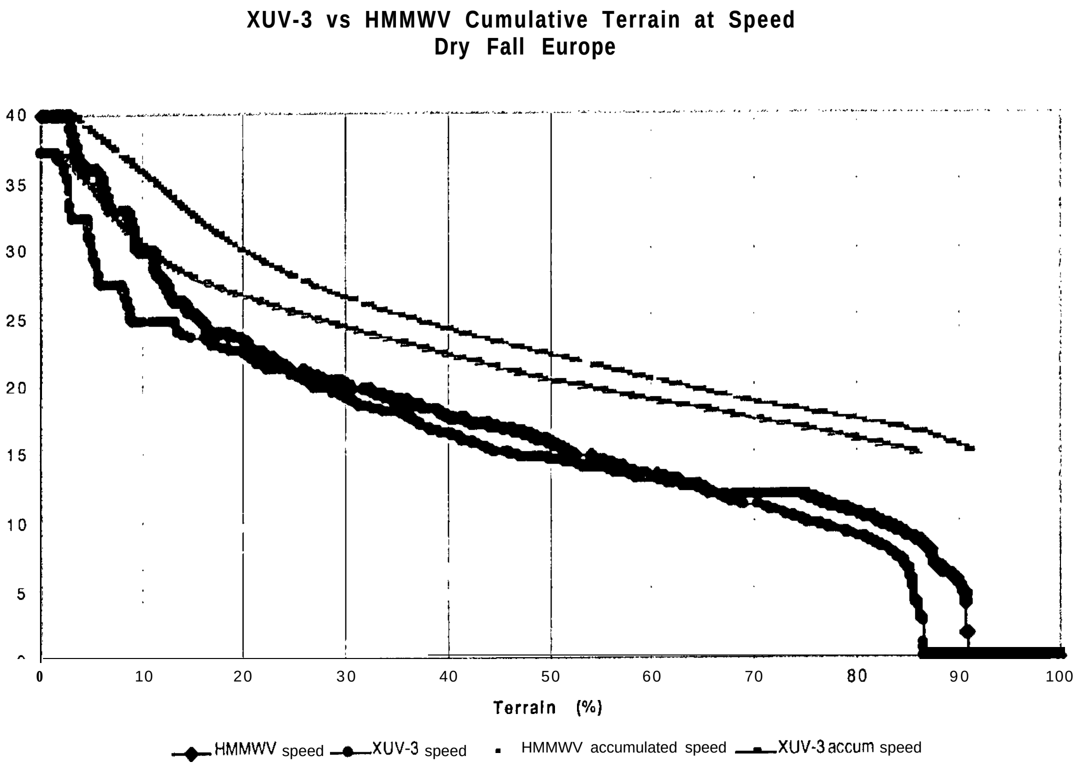


Figure 9. Comparison of Velocity Profiles

The average difference, in mph, between the two profiles is tabulated in Table 1.

Table 1. Average Difference for XUV3 and HMMWV Speed Profile

Average difference	*Europe*	*SW Asia*
Dry	1.7	3.6
Wet	1.9	2.9

A more commonly used comparison is between the so-called "V-80" speed of the two vehicles, taken from the accumulated speed profiles. The V-80 speed is the average speed of the vehicle over the easiest (highest achieved speed) 80% of the terrain. V-80 speeds are tabulated in Table 2, and their differences tabulated in Table 3. Note that V-70 speeds (average speed over the easiest 70% of the terrain) were used for the Wet Europe condition, as V-80 speeds were not defined.

Table 2. V-80 Speeds for HMMWV and XUV3

	Vehicle	Europe	SW Asia
DRY	HMMWV	17.3	15.6
	xuv3	15.9	14.8
WET	HMMWV	17.2”	15.6
	xuv3	15.3”	14.2

* Indicates V-70 Speed

Table 3. Difference of V-80 Speeds Between HMMWV and XUV3

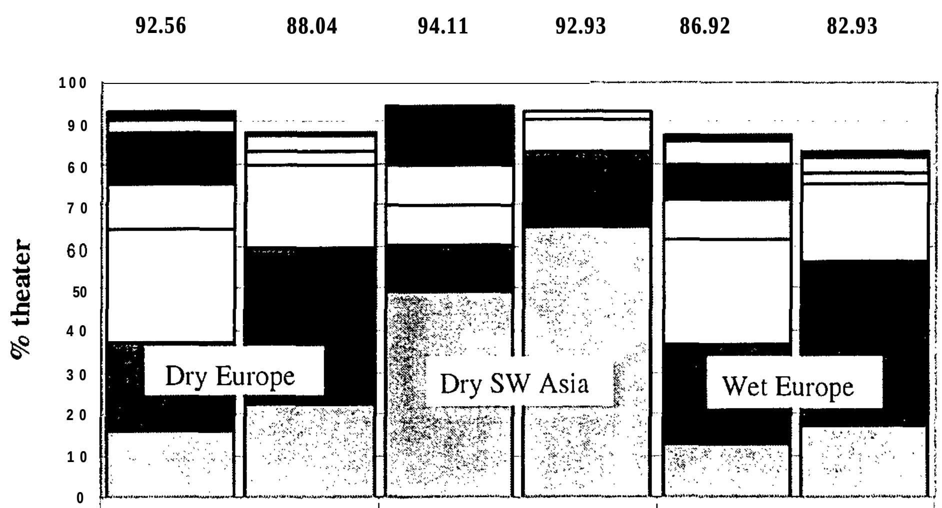
Delta MPH	Europe	SW Asia
Dry	1.4	0.8
Wet	1.9*	1.4

* Indicates V-70 Speed

Also of interest are differences in the amount of terrain that can be traversed, and the reasons limiting the speed. The difference in the amount of terrain traversable is tabulated in Table 4. In Figures 10 and 11, **the** NRMM program printouts of these values have been reformatted to emphasize the contrast. Figure 10 presents the percent of terrain that can be traversed by each vehicle, along with a table of speed limiting factors. Figure 11 presents the percent of terrain that could not be traversed. The results from Southwest Asia under wet/slippery conditions were not graphed because they were nearly identical to those from the dry conditions.

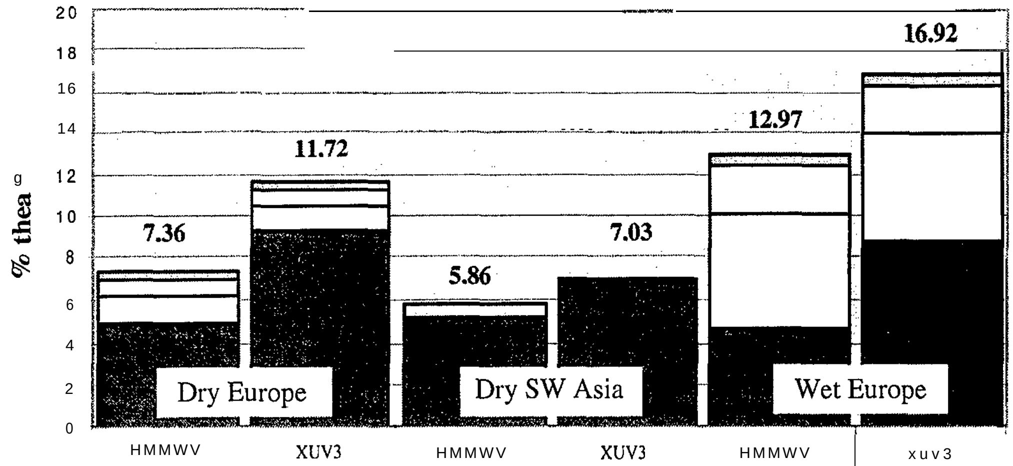
Table 4. Difference of Terrain Traversable Between HMMWV and XUV3

Delta %	Europe	SW Asia
Dry	4.4	1.2
Wet	4.0	1.2



	HMMWV	XUV3	[illegible]	[illegible]	HMMWV	XUV3
Maneuver around veg (over obs)	0.36	0.21			0.33	0.29
Obstacle impact	1.07	0.53		0.18	1.02	0.4
Soil & vegetation resistance	3.22	4.59	0.21		5.63	4.38
TireSpeed Limit	12.16		14.06		6.18	
Maneuver around obs and veg	11.06	2.62	9.27	1.75	9.61	2.61
Obstacle override force	27.24	19.9	9.75	7.5	25.41	16.49
Visibility	21.14	37.63	11.42	16.36	23.56	39.43
Ride Quality	16.29	22.36	49.4	65.14	12.96	17.33

Figure 10. Go Factors for HMMWV and XUV3



	HMMWV	XUV3	HMMWV	XUV3	HMMWV	xuv3
Obstacle Override						
Soil						
Tipping						
Belly interference			0.62			
Vegetation Override	0.37	0.43			0.52	0.59
Braking	0.79	0.81			2.24	2.28
Soil resistance	1.17	1.15			5.54	5.28
Obstacle interference	5.03	9.33	5.24	7.03	4.67	8.77

Figure 11. No-Go Factors for XUV3 and HMMWV

4.3 Discussion

An interesting comparison is a scatter plot comparing each vehicle's speed over the same terrain element, shown in Figure 12. The overall shape (generally following the line with slope 1.0) reinforces the notion that the XUV3 is slightly slower but generally comparable to the HMMWV over the same terrain. Questions are raised by the spike at HMMWV speed of 12 mph, and by the deterministic-looking set of points tracking a line with slope roughly 0.8. A variant of this plot (shown in Figure 13), with point color keyed to the limiting factor, is enlightening. From this graph and others like it, oddities in the shape of the plot can be explained. The mysterious vertical spike comes from a 12-mph speed limit imposed by the tire inflation pressure selected by the HMMWV model for traversing sandy soil. The tire pressure prescribed for the XUV3 is suitable for speeds up to the vehicle top speed, so there is no corresponding horizontal spike. The line at slope 0.8 is composed of terrain units where visibility is the limiting factor. NRMM models visibility as a linear function of the height of the driver's eye (for XUV3, the height at the top of the bodywork was taken as the likely location of the driving sensors), so it makes sense that the comparison is also linear.

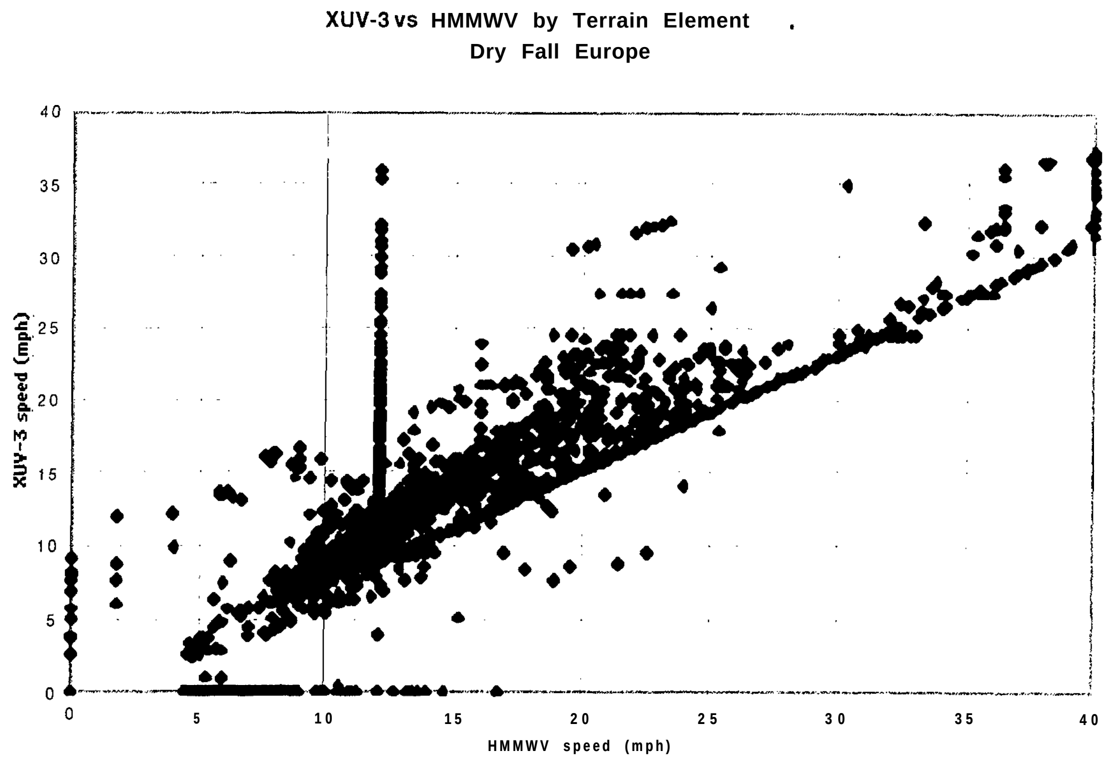


Figure 12. Scatter Plot by Terrain Element

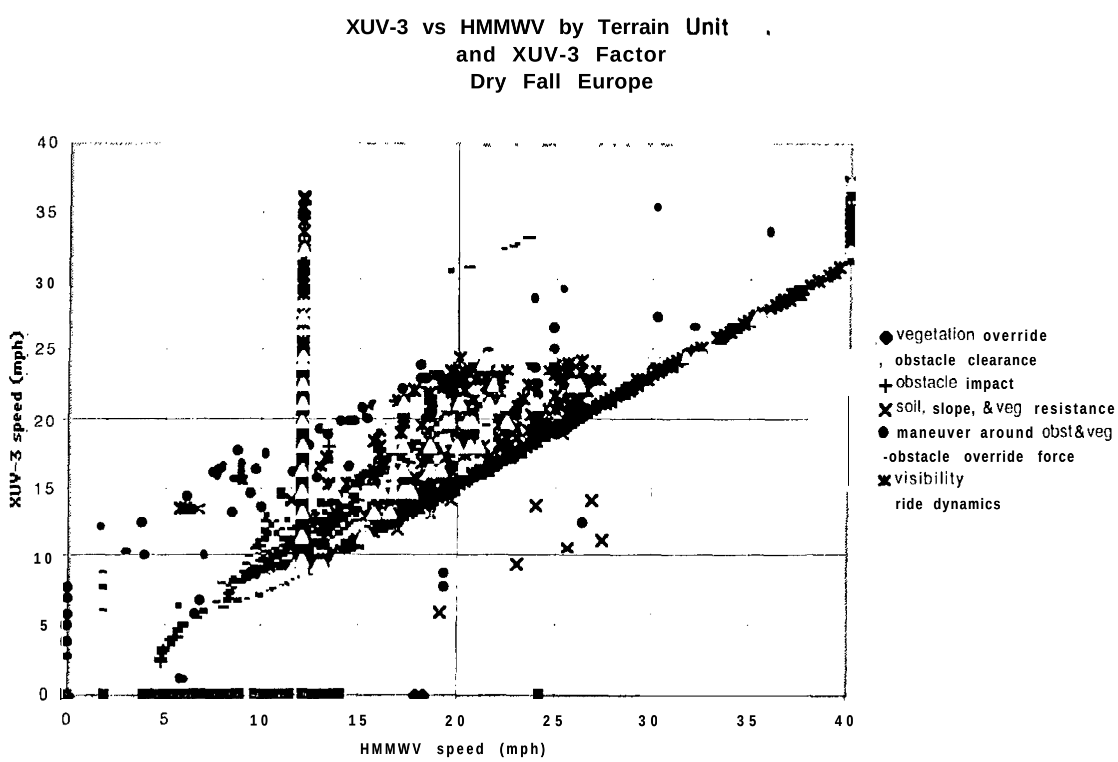


Figure 13. Scatter Plot by Terrain Element, by XUV3 Limiting Factor

Many of the terrain elements that are traversed faster by the XUV3 are speed-limited by the necessity of maneuvering around objects. It is reasonable that the narrower, shorter XUV3 with its tighter turning circle can maintain a higher speed in these circumstances.

The Go/No-Go predictions also deserve a closer analysis. Note that in each case the No-Go statistics for both vehicles are dominated by obstacle interference and the XUV3 is able to traverse several percent less terrain than is the HMMWV. In fact, the difference in obstacle interference completely accounts for the difference in No-Go statistics. Obstacle crossing in NRMM is a table lookup process from data output by the model described in section 3, and is thus a completely 2-D process. The larger tires and higher centerline ground clearance of the HMMWV are the probable explanation for the HMMWV's advantage in this domain.

The Go factors are more complicated to analyze. There are big differences in the factors governing the speed at which the two vehicles can traverse terrain, though the overall differences in speed attained remain fairly small, as shown in Tables 1 and 3. It is surprising to note that the much more powerful HMMWV is limited by the "obstacle override force" factor substantially more often than is the XUV3, but a closer look at the "by terrain element" data reveals that the XUV3 is limited by the "ride-quality" and "visibility" factors over that same terrain, at speeds very much the same. Further study is necessary to make sense of all the Go factor data.

5. Conclusions

The predicted mobility of the XUV3 was qualitatively similar to that of the HMMWV in both the European and Southwest Asian theaters and under conditions of dry and wet/slippery soil. In general, the model predicted the XUV3 could traverse a few percent less of the terrain than the HMMWV, at speeds averaging 2-4 mph slower than the HMMWV. The limiting factors resulting in the increased No-Go statistics were consistent with the lower tractive force and lower ground clearance of the XUV3. Limiting factors resulting in the decrease in ground speed were consistent with lower tractive force and lower sensor height of the XUV3. So the results were consistent with expectation and with trade-offs made in the design of the XUV3.

The 2-4 mph decrease in predicted average speed over terrain in comparison to the HMMWV satisfies the "20 mph over terrain a HMMWV can traverse at 25 to 30 mph" criterion proposed by some as a test of adequacy for the small chassis. The results are primarily based on differences in vehicle chassis characteristics. Other than eye height, the same driver constraints are used for the HMMWV and the XUV3. This evaluation of the performance of the XUV3 has pointed to the need for further research in the effects of autonomous mobility on UGV mobility evaluations. The effects of autonomous mobility technology on vehicle speed over terrain are yet to be assessed. Future efforts at ARL will model these effects, but proof will have to await testing of the XUV3 in suitably challenging terrain.

6. References

1. Ahlvin, D., and P. Haley. "NATO Reference Mobility Model Edition II, NRMM II User's Guide." Technical Report Number GL-92- 19, U.S. Army Waterways Experiment Station, Corps of Engineers, Vicksburg, MS, December 1992.

2. Creighton, D. "Revised Vehicle Dynamics Module: User's Guide for Computer Program VEHDYN II." Technical Report Number SL-86-9, U.S. Army Waterways Experiment Station, Corps of Engineers, Vicksburg, MS, May 1986.

3. Haley, P., M. Jurkat, and P. Brady, Jr. "NATO Reference Mobility Model, Edition I Users Guide, Volume II." Technical Report Number 12503, U.S. Army Tank-automotive and Armanments Command, Warren, MI, October 1979.

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Appendix A:

NATO Reference Mobility Model (NRMM) Main Module

A.1 Vehicle Data Input File for Experimental Unmannned Ground Vehicle 3 (XUV3): XUV3.dat

```
XUV3, DEMO III UGV (RST Inc)
 Project: XUV Ver 3
 Date entered: 20 August 1998
!Date revised: 20 August 1998; Timothy Vong
 File name:XUV3.STD
 Description:
XUV3, DEMO III UGV (RST Inc), ver# corresponds t oJeff Robertson ver#
 $VEI-IICLE
!**Basic information
  NAMBLY= 2,
  WGHT( 1)=1182,13 18,   ! Jeff Robertson chassis info dated 7/27/98
! **Geometric information
  CGH =27.0,        ! Jeff Robertson chassis info dated 7/27/98
  CGLAT = 0.0,
  CGR = 35.0,       ! Jeff Robertson 7/27/98 (horizontal, cg to rear axle)
  CL = 12.0,        ! Jeff Robertson chassis info dated 7/27/98
! (Ground clearance = @ ctr of hull, min. elsewhere,
  CLRMIN( 1)=9.5,9.5, !Tim calculation from Jeff 7/27/98 (@wheel arm!)
 !VAA = 90,         !TR-GL-92- 17
 !VDA = 45,         !TR-GL-92- 17
! **Recognition distance information
  EYEHGT=42.0,       ! RFP report (top of vehicle)
! **Vegetation performance information
  NVUNTS = 1,
  PBF =1600,        !Max push bar force(lb), assumed
  PBHT = 12.0,       ! assumed(bumper)
  VULEN( 1)=1 11 .O,   ! Jeff Robertson 7/27/98 (74+18.5+18.5) (vehicle length)
  WDTH =65.8,       ! Jeff Robertson 7/27/98 (56+9.8)(vehicle width)
!**Aerodynamic information
  ACD = .8,          ! Brad Beeson calculation sheet
  PFA = 13.5,        ! Tim calculated (ft^2)
! **Traction assembly information
  NVEH(1) = 1,1,
  TL=74.0,          ! Jeff Robertson 7/27/98 (wheel base)
! WI(1)   =          !n/u, NRMM II; NRMM-mgr
  WT( 1)  =56.0,56.0,! Jeff Robertson 7/27/98 (front/rear width tire center)
  WTE(l)  =46.2,46.2,! tire Sect. width (9.8") (front/rear width tire inside)
!**Track information
  ASHOE    =, !N/A
  GROUSH(1) =, !N/A
  NBOGIE(l) =,!N/A
  NFL(1)   =, !N/A
  NPAD(1) =,  !N/A
  RW(1)    =, !N/A
  TRAKLN(1) =, !N/A
  TRAKWD(l) =,!N/A
! **Wheel/tire information
  AVGC=63,! [lbs/deg] (cornering/lateral stiffness/hor. spring rate)
! assume 10% of wheel load if none of previous available, Nancy Saxon; 10% of (591+659)/2
  AXLSP( 1)=74.0,! Jeff Robertson 7/27/98 (axle spacing)
```

```
 NJPSI = 1,
 DFLCT(1,1)=0.663,0.705,! ARL Measured (25 psi Avg. load 591 front, 659 rear)
 !DFLCT(1,1)=1.2,1.7, !HWY
 !DFLCT( 1,3)=1.6,2.2,!SAND
 !DFLCT( 1,4)=1.8,2.4, !EMER
 DIAW( 1) =29.0,29.0,!Dunlop Tire Inc.
 ICONST( 1)=1,1, !1=Radial 2=Bias
 ID(l) = 0,0,
 IT(1) = 0,0,
 JVPSI = 1,
 KCTIOP(1)= 1,1,1,1,1,1,1,1,
 KTSFLG(l)= 1,1, !O=stiffness ignored 1=flexible 2=medium 3=stiff
 NCHAIN( 1)= 0,0,
 NWHL(1) = 2,2,
 RDIAM( 1) = 15.0,15.0, !front,rear from DUNLOP Tire Inc.
 RIMW(1) = 6.5,6.5, !front,rear from DUNLOP Tire Inc.
 SECTH( 1) = 7.0, 7.0, !front,rear from DUNLOP Tire Inc.
 SECTW(1) =9.8,9.8,! DUNLOP Tire Inc.
 TIREID( 1)='Dunlop Radial Mud Rover LT235/75R15','Same as front ',
 TPLY( 1) =6,6,
 TPSI(1,1)=25,25, ! ARL data
 !TPSI( 1,2)=23,23, !cold inflation pressure for single tire loads at
 !TPSI(1,3)=17,17, !speeds of 5,12,40 and 60 mph PSI'S chosen were
 !TPSI(1,4)=15,15, !for tire load of 25001bs although Ml025 tire
 VTIRMX( 1)=100,100 !mph, assumed at 25 psi, conversation with Jeff
!**Side-slope performance information; "zeroed" to remove slippage for NRMM calculation
 HROSUS( 1) = ! 15.0, 15.0; (Roll Center) Conversation with Jeff Robertson, RST
 NSUSP = ! 2; derived from VEHDYNII
 RAID( 1) = ! 146.0, 165.0; derived 7/27/98 presentation, RST(f=1023/7, r=1157/7)
!**Powertrain: fax received from AM general information FEB.94
!          fax no. 6225256l-xls 2/2/94 BGV & 6225256H.XLS 2/1/94 BGV
! IAPG =,! n/u, NRMM-II
 IP(1) =1,1,
!**Powertrain: engine information (from Kubota brochure, provided by
!Anthony DeMarco of Engine Distributors, Inc. (800)220-2700
! CID= 61.12, !Kubota D1005-B( E model are same)
! IDIESL= 1,
! IENGIN= 3, !number of data pts. describing rpm vs torque curve
! TARDEC origin unknown
! ENGINE(2,1)= 1600,34, !net continuous rpm vs torque
! ENGINE(2,2)= 2400,34, !net continuous rpm vs torque
! ENGINE(2,3)= 3600,33, !net continuous rpm vs torque
! HPNET =22.5, !net continuous hp
! NCYL = 3,
! NENG= 1,
! QMAX =34, !maximum net continuous torque
! **Power-train: transmission information
! ICONVl=O,
! CONVl= ,,
! ICONV2= 0,
! CONV2 = , ,
! ITCASE = 0, ! not used in NRMM-II
! ITRAN = 1, ! not used in NRMM-II
! ITVAR = 1,
! KTROPR= 8*0, !Best=O
! LOCKUP = 0,
```

```
!  NGR  =  0,
! NTRANG  = 1,
!  TCASE(1)=1.0,1.0,
! TQIND  =  ,
!  TRANS(1,1,1)=1,1,
!**Powertrain: Final drive information
  FD(l)  =1,1,
  LOCDIF=  1,
  REVM( 1) =695.5,695.5,!USED DFLCT OF 0" TO CALCULATE (Mile* 12/2*pi*r)
! **Power-train: Braking information
   IB(l)  =1,1,
   XBRCOF= .8,        ! assume same as used by M 1025 HMMWV run
!**Powertrain: tractive force vs. speed
!TF FROM Brad Beeson calculations at 60 Hp curve
  IPOWER=10
!          SPEED(mph)   TF(lbs)            HP
  POWER= 0.000000       1600.00     !     0.000000
         1.00000        1600.00     ! xx
         6.5000         1600.00     ! xx
         12.0000        1200.00     ! xx
         15.0000         825.00     ! xx
         20.0000         675.00     ! xx
         25.0000         575.00     ! xx
         30.0000         475.00     ! xx
         35.0000         400.00     ! xx
         38.0000         350.00     ! xx
! **Ride dynamics data
  MAXL=  1,
  ABSPWR(1)= 6,
  MAXIPR=12, !VEHDYNII Run + Excel Sheet Compiled (xuv3.vd2, 8/98)
  KVRIND(1)= 1,
    RMS(1)=0,.19,.34,.66,.86,1.20,1.81,2.17,3.27,3.49,4.0,5.0
! Speed (mph) at 6-WATTS
   VRIDE(1,1,1)=40,40,40,24.57,24.57,19.69,9.56,8.6,7.29,6.7,6.21,5.0
! **Obstacle height-speed
  NHVALS    =9,! VEHDYNII Run + Excel Sheet Compiled (xuv3.vd2, 8/98)
  KOHIND( 1) = 1,
   HVALS(l)  =0,1,2,3,4,6,8,10,18,
! Speed (mph) at 2.5gs over obstacle height
   VOOB(1,1) =40,40,40,40,40,17.93,10.05,3.37,2.38,
! **Ride: Obstacle spacing vs. speed
! NSVALS  =
! SVALS  =
! VOOBS  =
!* *Water crossing information
  CD   =   .7,
  DRAFT=,
  FORDD =30,
  SAE  =58,
  SAI  =69,
  VFS  = 5,
  vss   =   ,
  VSSAXP=  ,
  WC   =  ,
  WDAXP=  ,
!  **NRMM-mgr
```

```
 NWR = ,
 WDPTH( 1)=,
 WRAT(l) = ,
 WRFORD= ,
$END
NOHGT !OBS78B Version of: 24 April, 1990
   3 !Date: 20-August-1998
NANG !Vehicle file: XUV3.VEH
   8 !Obstacle file: WHEELS.OBS
NWDTH
   3
```

CLRMIN INCHES	FOOMAX POUNDS	FOO POUNDS	HOVALS INCHES	AVALS RADIANS	WVALS INCHES
8.85	963.0	38.4	3.15	1.95	5.88
-3.75	2000.1	95.8	15.75	1.95	5.88
-21.10	2001.6	185.2	33.46	1.95	5.88
8.85	971.4	34.9	3.15	2.48	5.88
-3.70	1005.1	126.7	15.75	2.48	5.88
-10.77	795.0	124.4	33.46	2.48	5.88
8.85	660.4	42.2	3.15	2.69	5.88
-3.05	648.5	108.6	15.75	2.69	5.88
-3.43	1031.6	122.5	33.46	2.69	5.88
8.85	390.1	33.3	3.15	2.86	5.88
2.54	356.2	55.5	15.75	2.86	5.88
2.48	689.1	96.5	33.46	2.86	5.88
8.26	397.6	39.8	3.15	3.42	5.88
3.54	429.0	75.1	15.75	3.42	5.88
2.97	689.1	102.5	33.46	3.42	5.88
8.75	673.4	47.2	3.15	3.60	5.88
1.06	728.0	134.1	15.75	3.60	5.88
-2.07	911.3	133.7	33.46	3.60	5.88
9.96	590.2	14.0	3.15	3.80	5.88
-1.30	1114.2	126.8	15.75	3.80	5.88
-4.45	1241.1	208.0	33.46	3.80	5.88
11.50	276.4	1.8	3.15	4.33	5.88
7.81	861.3	25.0	15.75	4.33	5.88
-3.22	2199.2	149.1	33.46	4.33	5.88
8.85	1009.4	25.4	3.15	1.95	29.88
-3.81	2043.1	123.8	15.75	1.95	29.88
-18.75	1903.4	123.7	33.46	1.95	29.88
8.85	971.4	28.1	3.15	2.48	29.88
-2.12	963.2	79.3	15.75	2.48	29.88
-2.84	1266.6	154.3	33.46	2.48	29.88
8.85	661.0	31.4	3.15	2.69	29.88
1.98	504.2	50.5	15.75	2.69	29.88
1.78	973.5	130.4	33.46	2.69	29.88
8.85	390.1	28.7	3.15	2.86	29.88
5.51	428.6	59.2	15.75	2.86	29.88
5.51	689.1	102.1	33.46	2.86	29.88
8.40	397.6	34.9	3.15	3.42	29.88
4.46	428.5	61.5	15.75	3.42	29.88
4.53	689.1	105.6	33.46	3.42	29.88
8.34	674.8	33.7	3.15	3.60	29.88
0.87	734.0	107.9	15.75	3.60	29.88
0.05	1036.8	142.8	33.46	3.60	29.88
8.06	961.1	35.1	3.15	3.80	29.88

-1.50	1123.1	131.1	15.75	3.80	29.88
-4.65	1255.6	164.6	33.46	3.80	29.88
8.06	1039.8	41.4	3.15	4.33	29.88
-7.65	2217.0	171.8	15.75	4.33	29.88
-99.00	2217.0	171.8	33.46	4.33	29.88
8.85	977.9	13.2	3.15	1.95	141.60
-3.75	2205.0	72.1	15.75	1.95	141.60
-10.44	2324.3	154.0	33.46	1.95	141.60
8.85	1038.2	17.2	3.15	2.48	141.60
1.31	1133.6	75.0	15.75	2.48	141.60
-0.16	1266.6	146.3	33.46	2.48	141.60
8.85	673.5	16.6	3.15	2.69	141.60
3.68	728.7	63.5	15.75	2.69	141.60
3.61	973.5	125.2	33.46	2.69	141.60
8.85	397.7	16.0	3.15	2.86	141.60
6.70	428.6	61.5	15.75	2.86	141.60
6.71	689.1	94.2	33.46	2.86	141.60
8.99	397.5	18.2	3.15	3.42	141.60
6.74	427.9	61.2	15.75	3.42	141.60
6.64	689.1	93.2	33.46	3.42	141.60
8.85	674.6	19.4	3.15	3.60	141.60
3.74	729.1	68.8	15.75	3.60	141.60
3.57	1031.5	128.2	33.46	3.60	141.60
9.05	1038.2	17.3	3.15	3.80	141.60
1.28	1121.5	76.0	15.75	3.80	141.60
-0.14	1265.0	162.1	33.46	3.80	141.60
8.85	1061.3	21.1	3.15	4.33	141.60
-3.50	2205.2	71.8	15.75	4.33	141.60
-10.15	2297.7	156.3	33.46	4.33	141.60

A.2 Vehicle Data Input File for U.S. Army Waterways Experiment Station (WES) High-Mobility, Multipurpose, Wheeled Vehicle (HMMWV): M1025wes.dat

```
HMMWV, M1025, ARMAMENT CARRIER (WES STANDARD)
 Project: Standard Vehicle
 Date entered: 10 MARCH 94
 File name:M1025.STD
 Description:
 HMMWV, M1025, ARMAMENT CARRIER (WES STANDARD)
 $VEHICLE
! **Basic information
  NAMBLY= 2,
  WGHT(1)=3000,4500,   !TM 9-2320-280-10
! **Geometric information
  CGH =32.8,       !AMC GENERAL FAX FEB 94
  CGLAT = 0,
  CGR =50.5,       !AMC GENERAL TR-GL-92-7
  C L =11.3,      !TR-GL-93- 15
! (Ground clearance = @ ctr of hull, min. elsewhere,
  CLRMIN(1)=11.3,11.3, !TR-GL-93-15
```

```
 !VAA = 90,          !TR-GL-92- 17
 !VDA = 45,          !TR-GL-92- 17
! **Recognition distance information
  EYEHGT=62,          !GL-93-15
! **Vegetation performance information
  NVUNTS = 1,
  PBF =7500,          !TM9-2320-280-10
  PBHT =24.8,         !GL-93-15
  VULEN( 1 )= 180,    !TM9-2320-280- 10
  WDTH =85,           !TM9-2320-280- 10
! **Aerodynamic information
  ACD = .7,
  PFA =35.3,          !AMC General Fax Feb94
! **Traction assembly information
  NVEH(l) = 1,1,
  TL=130,             ! TR-GL-92- 17
! WI(1)   =           !n/u, NRMM II; NRMM-mgr
  WT(1) =71.6,71.6, !TR-GL-93-15
  WTE(l) =59.1,59.1, !TR-GL-93-15
! **Track information
  ASHOE    =, !N/A
  GROUSH( 1) =,!N/A
  NBOGIE(l) =,!N/A
  NFL(1)    =, !N/A
  NPAD(1) =, !N/A
  RW(1)     =, !N/A
  TRAKLN(l) =,!N/A
  TRAKWD(l) =,!N/A
! **Wheel/tire information
  AVGC=188,
  AXLSP(1) =130,
  NJPSI = 4,
  DFLCT( 1 ,1)=1.2,1.7,!HWY  See note on PSI input for Source of PSI's and
  DFLCT( 1,2)=1.4,1.9, !CC   Deflections calculated from Goodyear load, PSI
  DFLCT(1,3)=1.6,2.2,!SAND Deflection curve MD-327477 2/7/92
  DFLCT(1,4)=1.8,2.4, !EMER
  DIAW( 1) =36.6,36.6,!GOODYEAR
  ICONST(1)= 1,1,
  ID(l) = 0,0,
  IT(l) = 0,0,
  JVPSI = 1,
   KCTIOP( 1)=1,1,3,2,3,3,2,3,
  KTSFLG( 1)=1,1,   ! 1 =Radial 2=Bias
  NCHAIN( 1)= 0,0,
  NWHL(l) = 2,2,
  RDIAM(1) =16.5,16.5, !Tireid
  RIMW(1) = 8.25,8.25, !MD-409522
  SECTH(1) = 9.2, 9.2, !Wes Field Tests, lo-1990
  SECTW( 1) =12.3,12.3, !Goodyear MD-409522
  TIREID( 1)='37X12.5R16.5LT RADIAL','37X12.5R16.5LT RADIAL ',
  TPLY (1) =4,4,
  TPSI( 1,1)=26,26,    !Fax from Joe Ripley Goodyear 4/5/93 table minimum
  TPSI( 1,2)=23,23,    !cold inflation pressure for single tire loads at
  TPSI(1,3)=17,17,     !speeds of 5,12,40 and 60 mph PSI'S chosen were
  TPSI(1,4)=15,15,     !for tire load of 2500lbs although Ml 025 tire
  VTIRMX( 1)=60,40,12,5,!load were 1500 for front and 2250 for rear & R.Jones
```

```
!**Side-slope performance information
  HROSUS( 1) =,! to be derived from VEHDYN data
  NSUSP     =,! to be derived from VEHDYN data
  RAID(1)    =,! assumes roll center is C-G;
!**Powertrain: fax received from AM general information FEB.94
!          fax no. 6225256l-xls 2/2/94 BGV & 6225256H.XLS 2/1/94 BGV
! IAPG =,! n/u, NRMM-II
  IP(1) =1,1,
!**Powertrain: engine information
  CID= 379,
  IDIESL= 1,
  IENGIN= 0,
! TARDEC origin unknown
   ENGINE=    , ,
   HPNET =150,!TM-9-2320-280- 10
   NCYL = 8, !TM-9-2320-280-10
   NENG = 1,
   QMAX =239,
!**Powertrain: transmission information
 ICONV1=0,
 CONV1 = , ,
 ICONV2= 0,
 CONV2 = , ,
! ITCASE = 0,   ! not used in NRMM-II
!ITRAN = 1,  ! not used in NRMM-II
 ITVAR = 0,
 KTROPR = 8*0, !Best=O
 LOCKUP = 1,
 NGR = 6,
 NTRANG = 1,
 TCASE(1)=1.0,1.0,
 TQIND = ,
  TRANS(1,1,1)=6.47,.96,
             3.86,.96,
             2.61,.96,
             2.48,.96,
             1.48,.96,
             1.0 ,.96,
!**Powertrain: Final drive information
  FD( 1) =4.92,.96,
 LOCDIF= 1,
 REVM( 1) =583,583,!USED CC DFLCT OF 2.0" TO CALCULATE
!**Powertrain: Braking information
  IB(l) =1,1,
  XBRCOF= .8,
!**Powertrain: tractive force vs. speed
! TEMPLE'S FILES-NO DOCUMENTED SOURCE
! IPOWER= 2 1,
! POWER= 0 ,7550,
!        1 ,6840,
!        2 ,6185,
!        3 ,5690,
!        5 ,4760,
!        7 ,4195,
!        9 ,4100,
!       11 ,3785,
```

```
!        13 ,2495,
!        19 ,2265,
!        22 ,1721,
!        27 ,1600,
         29 ,1530,
!        31 , 955,
!
!        35 40 ,950, ,930,
!        45 ,890,
!        50,655,
!        60,640,
!        70 ,600,
!        73 ,600,
! TF FROM AMC GENERAL SCAAN DATA 2-l-94
 IPOWER=80
!        SPEED        TF            HP
 POWER=  0.000000     5880.00    !    0.000000
      1 .00000      5880.00    !    15.6800
      2.00000       5880.00    !    31.3600
      3 .00000      5880.00    !    47.0400
      4.00000       5880.00    !    62.7200
      5.00000       5638.00    !    75.1733
      6.00000       5122.03    !    81.9524
      7.00000       4744.07    !    88.5559
      8.00000       4690.76    !    100.069
      9.00000       4602.20    !    110.453
     10.0000        4444.97    !    118.533
     11 .0000       4269.86    !    125.249
     12.0000        2867.76    !    91.7683
     13 .0000       2860.82    !    99.1751
     14.0000        2841.23    !    106.072
     15.0000        2805.02    !    112.201
     16.0000        2753.97    !    117.503
     17.0000        2689.97    !    121.945
     18.0000        2628.29    !    126.158
     19.0000        2555.78    !    129.493
     20.0000        2490.25    !    132.813
     2 1 .0000      1952.42    !    109.336
     22.0000        1935.77    !    113.565
     23.0000        1914.37    !    117.415
     24.0000        1887.40    !    120.794
     25 .0000       1857.46    !    123.83 1
     26.0000        1829.31    !    126.832
     27.0000        1800.02    !    129.602
     28.0000        1764.91    !    131.780
     29.0000        1731.13    !    133.874
     30.0000        1592.05    !    127.364
     3 1 .0000      1565.95    !    129.452
     32.0000        1092.49    !    93.2258
     33.0000        1091.43    !    96.0454
     34.0000        1089.64    !    98.7944
     35 .0000       1087.38    !    101.489
     36.0000        1084.45    !    104.108
     37.0000        1081.00    !    106.659
     38.0000        1076.00    !    109.035
     39.0000        1070.23    !    111.304
```

```
     40.0000        1063.92          113.485
     41.0000        1056.28          115.487
     42.0000        1048.02      !   117.379
     43.0000        1038.99          119.137
     44.0000        1029.48      !   120.793
     45.0000        1019.94      !   122.393
     46.0000        1011.12          124.030
     47.0000        1002.23          125.613
     48.0000        993.245          127.135
     49.0000        982.456          128.374
     50.0000        971.171      !   129.489
     51.0000        960.411      !   130.616
     52.0000        951.206      !   131.901
     53.0000        943.081      !   133.289
     54.0000        743.197      !   107.020
     55.0000        741.438      !   108.744
     56.0000        739.354      !   110.410
     57.0000        737.271      !   112.065
     58.0000        734.430      !   113.592
     59.0000        731.477      !   115.086
     60.0000        728.117      !   116.499
     61.0000        724.351      !   117.828
     62.0000        720.551      !   119.131
     63.0000        716.469      !   120.367
     64.0000        712.388      !   121.581
     65.0000        708.084      !   122.735
     66.0000        703.667      !   123.845
     67.0000        699.333      !   124.948
     68.0000        695.412      !   126.101
     69.0000        691.490      !   127.234
     70.0000        687.272      !   128.291
     71.0000        682.872      !   129.290
     72.0000        678.390      !   130.251
     73.0000        673.305      !   131.070
     74.0000        668.220      !   131.862
     75.0000        663.168      !   132.634
     76.0000        658.126      !   133.380
     77.0000        653.581      !   134.202
     78.0000        649.846      !   135.168
     79.0000        646.112      !   136.114
!FROM PETER HALEY'S VEHICLE FILE HMMWV-WC-HIGH
!IPOWER = 141
!      SPEED        TF            HP
!POWER= 0.000000     2893.00     !  0.000000
!      0.500000     2834.25     !  3.77900
!      1.00000      2775.50     !  7.40133
!      1.50000      2716.75     !  10.8670
!      2.00000      2658.00     !  14.1760
!      2.50000      2614.25     !  17.4283
!      3.00000      2570.50     !  20.5640
!      3.50000      2526.75     !  23.5830
!      4.00000      2483.00     !  26.4853
!      4.50000      2441.25     !  29.2950
!      5.00000      2399.50     !  31.9933
!      5.50000      2357.75     !  34.5803
!      6.00000      2316.00     !  37.0560
```

!	6.50000	2279.25	!	39.5070
!	7.00000	2242.50	!	41.8600
!	7.50000	2205.75	!	44.1150
!	8.00000	2169.00	!	46.2720
!	8.50000	2134.25	!	48.3763
!	9.00000	2099.50	!	50.3880
!	9.50000	2064.75	!	52.3070
!	10.0000	2030.00	!	54.1333
!	10.5000	1996.00	!	55.8880
!	11.0000	1962.00	!	57.5520
!	11.5000	1928.00	!	59.1253
!	12.0000	1894.00	!	60.6080
!	12.5000	1859.75	!	61.9917
!	13.0000	1825.50	!	63.2840
!	13.5000	1791.25	!	64.4850
!	14.0000	1757.00	!	65.5947
!	14.5000	1721.75	!	66.5743
!	15.0000	1686.50	!	67.4600
!	15.5000	1651.25	!	68.2517
!	16.0000	1616.00	!	68.9493
!	16.5000	1604.00	!	70.5760
!	17.0000	1592.00	!	72.1707
!	17.5000	1580.00	!	73.7333
!	18.0000	1568.00	!	75.2640
!	18.5000	1566.75	!	77.2930
!	19.0000	1565.50	!	79.3187
!	19.5000	1564.25	!	81.3410
!	20.0000	1563.00	!	83.3600
!	20.5000	1559.75	!	85.2663
!	21.0000	1556.50	!	87.1640
!	21.5000	1553.25	!	89.0530
!	22.0000	1550.00	!	90.9333
!	22.5000	1544.50	!	92.6700
!	23.0000	1539.00	!	94.3920
!	23.5000	1533.50	!	96.0993
!	24.0000	1528.00	!	97.7920
!	24.5000	1516.25	!	99.0617
!	25.0000	1504.50	!	100.300
!	25.5000	1492.75	!	101.507
!	26.0000	1481.00	!	102.683
!	26.5000	1480.75	!	104.640
!	27.0000	1480.50	!	106.596
!	27.5000	1480.25	!	108.552
!	28.0000	1480.00	!	110.507
!	28.5000	1348.75	!	102.505
!	29.0000	1217.50	!	94.1533
!	29.5000	1086.25	!	85.4517
!	30.0000	955.000	!	76.4000
!	30.5000	954.500	!	77.6327
!	31.0000	954.000	!	78.8640
!	31.5000	953.500	!	80.0940
!	32.0000	953.000	!	81.3227
!	32.5000	952.750	!	82.5717
!	33.0000	952.500	!	83.8200
!	33.5000	952.250	!	85.0677
!	34.0000	952.000	!	86.3147

!	34.5000	950.167	!	87.4153
!	35.0000	948.333	!	88.5111
!	35.5000	946.500	!	89.6020
!	36.0000	944.667	!	90.6880
!	36.5000	942.833	!	91.7691
!	37.0000	941.000	!	93.9167 92.8453
!	37.5000	939.167		
!	38.0000	937.333	!	94.9831
!	38.5000	935.500	!	96.0447
!	39.0000	933.667	!	97.1013
!	39.5000	931.833	!	98.1531
!	40.0000	930.000	!	99.2000
!	40.5000	925.667	!	99.9720
!	41.0000	921.333	!	100.732
!	41.5000	917.000	!	101.481
!	42.0000	912.667	!	102.219
!	42.5000	908.333	!	102.944
!	43.0000	904.000	!	103.659
!	43.5000	899.667	!	104.361
!	44.0000	895.333	!	105.052
!	44.5000	891.000	!	105.732
!	45.0000	886.667	!	106.400
!	45.5000	882.333	!	107.056
!	46.0000	878.000	!	107.701
!	46.5000	850.375	!	105.446
!	47.0000	822.750	!	103.118
!	47.5000	795.125	!	100.716
!	48.0000	767.500	!	98.2400
!	48.5000	739.875	!	95.6905
!	49.0000	712.250	!	93.0673
!	49.5000	684.625	!	90.3705
!	50.0000	657.000	!	87.6000
!	50.5000	656.400	!	88.3952
!	51.0000	655.800	!	89.1888
!	51.5000	655.200	!	89.9808
!	52.0000	654.600	!	90.7712
!	52.5000	654.000	!	91.5600
!	53.0000	653.400	!	92.3472
!	53.5000	652.800	!	93.1328
!	54.0000	652.200	!	93.9168
!	54.5000	651.600	!	94.6992
!	55.0000	651.000	!	95.4800
!	55.5000	649.900	!	96.1852
!	56.0000	648.800	!	96.8875
!	56.5000	647.700	!	97.5868
!	57.0000	646.600	!	98.2832
!	57.5000	645.500	!	98.9767
!	58.0000	644.400	!	99.6672
!	58.5000	643.300	!	100.355
!	59.0000	642.200	!	101.039
!	59.5000	641.100	!	101.721
!	60.0000	640.000	!	102.400
!	60.5000	638.000	!	102.931
!	61.0000	636.000	!	103.456
!	61.5000	634.000	!	103.976
!	62.0000	632.000	!	104.491

```
!     62.5000     630.000    !  105.000
!     63.0000     628.000    !  105.504
!     63.5000     626.000    !  106.003
!     64.0000     624.000    !  106.496
!     64.5000     622.000    !  106.984
!     65.0000     620.000    !  107.467
!     65.5000     618.000    !  107.944
!     66.0000     616.000    !  108.416
!     66.5000     614.000    !  108.883
!     67.0000     612.000    !  109.344
!     67.5000     610.000    !  109.800
!     68.0000     608.000    !  110.251
!     68.5000     606.000    !  110.696
!     69.0000     604.000    !  111.136
!     69.5000     602.000    !  111.571
!     70.0000     600.000    !  112.000
! **Ride dynamics data
  MAXL= 1,
  ABSPWR(1)= 6,
  MAXIPR=24,!TECHNICAL REPORT GL-92-7 Field Data or VEHDYN
  KVRIND(1)= 1,
    RMS(1)=0,.45,.45,.47,.5,.55,.6,.65,.7,.8,.85,.9,.95,1,1.1,1.18,1.2,1.3,
           1.34, 1.47, 2, 2.2, 2.4, 6,
! 6-WATTS VRIDE(1,1,1)=100,80,50,45,42,38,36,34,33,30,29,28,27,26.2,24,23,
           22.5,21,20,18,12,11,10.5,2,
! **Obstacle height-speed
  NHVALS =17,!TECHNICAL REPORT GL-92-7
  KOHIND( 1) =1,
   HVALS(l) =0, 4, 4, 4, 4.2, 4.4,4.5,4.9,5,5.5,6.2,7,8,8.3,9.3,10,100,
   VOOB(1,l) =100,100,50,38,30,25.5,21,17,16,14.5,13,14,12,9,7,5,2,
! **Ride: Obstacle spacing vs. speed
! NSVALS =
! SVALS =
! VOOBS =
!**Water crossing information
  CD = .7,
  DRAFT = ,
  FORDD =30,
  SAE =58,
  SAI =69,
  VFS = 5,
  vss = ,
  VSSAXP= ,
  WC = ,
  WDAXP= ,
!**NRMM-mgr
  NWR = ,
  WDPTH(1)= ,
  WRAT(1) = ,
  WRFORD= ,
 $END
 NOHGT OBS78B Version of: 24 April, 1990
   3 Date: 25-FEB-94 Time: 15:08:20
 NANG Vehicle file:M1025.OBV
   8 Obstacle file:C:\MSD\OBMOD\OBW.DAT
```

NWDTH STEPMN= 1.0000 STEPMX= 2.0000
3

CLRMIN INCHES	FOOMAX POUNDS	FOO POUNDS	HOVALS INCHES	AVALS RADIANS	WVALS INCHES
14.24	2996.4	105.4	3.15	1.95	5.88
1.64	6767.9	352.9	15.75	1.95	5.88
-16.07	6774.2	562.6	33.46	1.95	5.88
14.24	2996.4	106.7	3.15	2.48	5.88
1.48	3429.8	329.4	15.75	2.48	5.88
-16.09	3420.7	554.4	33.46	2.48	5.88
14.23	2249.6	82.4	3.15	2.69	5.88
1.49	2252.1	315.3	15.75	2.69	5.88
-11.41	2169.5	411.3	33.46	2.69	5.88
14.23	1346.0	94.7	3.15	2.86	5.88
1.65	1346.1	257.0	15.75	2.86	5.88
-0.28	1373.0	215.8	33.46	2.86	5.88
14.46	1357.7	89.7	3.15	3.42	5.88
8.30	1406.2	271.0	15.75	3.42	5.88
7.51	1477.2	252.9	33.46	3.42	5.88
15.00	2270.7	65.9	3.15	3.60	5.88
6.22	2363.0	297.1	15.75	3.60	5.88
2.35	2499.5	498.9	33.46	3.60	5.88
16.29	1553.5	35.5	3.15	3.80	5.88
6.57	3581.5	319.7	15.75	3.80	5.88
-2.61	3807.2	580.4	33.46	3.80	5.88
16.83	591.1	-2.5	3.15	4.33	5.88
15.17	2385.5	84.4	15.75	4.33	5.88
8.71	5835.3	209.7	33.46	4.33	5.88
14.24	2996.4	91.8	3.15	1.95	29.88
1.64	6767.9	312.3	15.75	1.95	29.88
-16.07	6774.2	505.9	33.46	1.95	29.88
14.24	2996.4	92.8	3.15	2.48	29.88
1.48	3429.8	293.5	15.75	2.48	29.88
-16.20	3420.7	504.7	33.46	2.48	29.88
14.23	2249.6	71.6	3.15	2.69	29.88
1.47	2252.1	283.5	15.75	2.69	29.88
-5.93	2077.2	302.0	33.46	2.69	29.88
14.23	1346.0	82.8	3.15	2.86	29.88
3.11	1329.6	212.6	15.75	2.86	29.88
2.94	1477.5	231.8	33.46	2.86	29.88
14.51	1358.0	80.4	3.15	3.42	29.88
8.22	1406.2	235.7	15.75	3.42	29.88
7.92	1475.5	239.9	33.46	3.42	29.88
14.53	2278.8	79.4	3.15	3.60	29.88
5.87	2372.7	301.7	15.75	3.60	29.88
2.34	2507.3	399.1	33.46	3.60	29.88
14.25	2932.1	80.6	3.15	3.80	29.88
4.45	3619.8	334.0	15.75	3.80	29.88
-3.62	3830.4	549.9	33.46	3.80	29.88
8.46	5609.7	184.4	3.15	4.33	29.88
3.65	7093.2	314.9	15.75	4.33	29.88
-18.09	7410.2	575.5	33.46	4.33	29.88
13.90	2967.7	54.3	3.15	1.95	141.60
3.43	7118.4	209.5	15.75	1.95	141.60
-9.66	7425.2	408.1	33.46	1.95	141.60
13.90	2967.7	54.7	3.15	2.48	141.60

4.26	3610.5	199.6	15.75	2.48	141.60
-3.46	3834.6	396.5	33.46	2.48	141.60
13.90	2277.8	57.5	3.15	2.69	141.60
5.54	2372.4	206.5	15.75	2.69	141.60
2.35	2502.5	350.1	33.46	2.69	141.60
13.97	1357.8	51.1	3.15	2.86	141.60
8.07	1406.1	175.5	15.75	2.86	141.60
7.93	1477.5	291.8	33.46	2.86	141.60
14.00	1358.0	48.7	3.15	3.42	141.60
8.11	1404.8	172.5	15.75	3.42	141.60
7.93	1477.0	290.6	33.46	3.42	141.60
13.98	2277.9	56.3	3.15	3.60	141.60
5.55	2368.7	201.7	15.75	3.60	141.60
2.34	2504.9	359.5	33.46	3.60	141.60
13.91	2802.3	41.1	3.15	3.80	141.60
4.42	3619.3	210.0	15.75	3.80	141.60
-3.44	3835.8	401.0	33.46	3.80	141.60
14.46	2908.5	40.0	3.15	4.33	141.60
3.61	7106.8	152.3	15.75	4.33	141.60
-17.21	7417.1	350.8	33.46	4.33	141.60

A.3 Example of Command Input File for XUV3: run.inp

```
! Anything after an "!" is ignored!!!
ECHO=ON        ! Enable echo of these input options on system output
! input=kbd          ! system input
!output=con !run.out    ! system output
!scratch=SCRATCH      ! Specify specific name for internal scratch files.
pred=predhv4.lau          ! prediction output
stats=stathv4.lau         ! Statistics output
! SPCL=special        ! Enable special (traverse, acdc etc.) output
CALL   =data\vehlist.inp ! Example of "call" to another input file
sfile=data\scenario.dat    ! scenario file
!  scenario=DRY-NORMAL    ! scenario #1
!  scenario=WBT-NORMAL    ! scenario #2
!  scenario=SNOW        ! scenario #3
!  scenario=SAND        ! scenario #4
!  scenario=WWET-SLIPRY   ! scenario #5
!  scenario=WET-SLIPRY    ! scenario #6
scenario=WET-SLIPRO     ! scenario #7
!tvfile=terrain/cktern.a90     ! Terrain file (check patch)
!tvfile=terrain/cktern.r90     ! Terrain file
tvfile=terrain/5322.a90       ! Terrain file (LAUTERBACH)
!tvfile=terrain/3254iv.a90     ! terrain file (MAFRAQ)
!tvfile=terrain/2756IV.A90      ! terrain file (Honduras)
!#VEH=2,1,3   ! (run 2 vehicles i.e. vehicle #1 & #3)
! (The following namelist may appear anywhere in the input or not at all.)
 $CONTRL
!  DETAIL=10, ! When enabled, this will print all diagnostics
!          ! (Which is not recommended except for one terrain unit)
!  KVEH=1,     ! When enabled, echos vehicle data input
!  KMAP=1,     ! When enabled, echos terrain data input
```

```
! KSCEN=1,   ! When enabled, echos scenario data input
! The above could also be accomplished by requestion the entire COMMOM
! name via the 'vnames' option as:
! VNAMES='VEHICL  TERRAN  SCEN'
! KTPP=1 ,    ! When enabled, echos inputs & outputs of terrain preprocessor
! KIV3 = 2    ! Would enable 'low level' diagnostics for routine IV3
! KIV(3)=2    ! Alternative to above
! KII(11)=3* 1  ! Would enable diagnostics for routines II 11, II 12, & II 13
! KTFPLT= 1,   ! When enabled, produces soil corrected TF vs. Speed plot for
!          ! slope case KUDL = 1 (up-slope.)
!  SEARCH=2, NTUX=1,5,! Would run only 2 terrain units; #1& #5
! VNAMES( 1 )='vcicmb'  ! When enabled, this will print combination VCI
 $END
```

A.4 Example of Vehicle List File for XUV3: vehlist.inp

```
! 21 August 1998
!List of vehicles for example
!(This file is "Called" by main module system input)
!VEHICLE= DATA\XUV1 .DAT
!VEHICLE= DATA\M1A1_F94.DAT
!vehicle= DATA\M1025_M94.DAT
! VEHICLE= data\mdarse.dat
!vehicle= data\mdars2.dat
!vehicle= data\m1025std.dat
VEHICLE= DATA\XUV3.DAT
```

A.5 Example of Scenario File for XUV3: scenario.dat

```
DRY-NORMAL
Dry,Normal,October
 $SCENAR
 MAPG=2,
 LAC=1,
 ISEASN=l, ISNOW= 0, ISAND= 0, ISURF= 1,
 NOPP=O, NSLIP= 0, MONTH= 10,
   COEFHD= 1 .O,
   GAMMA=. 10,
   ZSNOW=10.0,
   RDFOG=1000., REACT=.75, DCLMAX=2.0, SFTYPC=90.0,
   VBRAKE= 2.0, VISMNV= 2.0, VLIM= 100.0, VWALK= 4.0,
 $END
DRY,NORM,JUN
Dry,Normal,June
 $SCENAR
 !MAPG=2,
 LAC=1,
 ISEASN=1 . ISNOW= 0, ISAND= 0, ISURF=1,
 NSLIP= 0, MONTH=6,
   COEFHD= 1 .0,
   GAMMA=. 10,
```

```
  ZSNOW=10.0,
  RDFOG=1000., REACT=.75, DCLMAX=2.0, SFTYPC=90.0,
  VBRAKE= 2.0, VISMNV= 2.0, VLIM= 100.0, VWALK= 4.0,
 $END
WET-NORMAL
Wet,Normal,October
 $SCENAR
 !MAPG=2,
 LAC=1,
 ISEASN=3, ISNOW= 0, ISAND= 0, ISURF= 1,
 NOPP= 0, NSLIP= 0, MONTH=10,
  COEFHD=1.0, GAMMA=. 10, ZSNOW=10.0,
 RDFOG=1000., REACT=.75, DCLMAX=2.0, SFTYPC=90.0,
 VBRAKE= 2.0, VISMNV= 2.0, VLIM= 100.0, VWALK= 4.0,
 $END
WET,NORM,JAN
Wet,Normal,January
 $SCENAR
 !MAPG=2,
 LAC=1,
 ISEASN=3, ISNOW= 0, ISAND= 0, ISURF= 1,
 NOPP= 0, NSLIP= 0, MONTH= 1,
  COEFHD=1 .O, GAMMA=. 10, ZSNOW=10.0,
 RDFOG=1000., REACT=.75, DCLMAX=2.0, SFTYPC=90.0,
 VBRAKE= 2.0, VISMNV= 2.0, VLIM= 100.0, VWALK= 4.0,
 $END
WET-SLIPRY
Wet,Slippery,June
 $SCENAR
 !MAPG=2,
 LAC=1,
 ISEASN=3,
 ISNOW= 0,
 ISAND= 0,
 ISURF= 2,
 NOPP= 0,
 NSLIP= 1,
 MONTH=6,
  COEFHD=1 .O,
   GAMMA=. 10,
   ZSNOW=10.0,
 RDFOG=1000.,
 REACT=.75,
 DCLMAX=2.0,
 SFTYPC=90.0,
 VBRAKE= 2.0,
 VISMNV= 2.0,
 VLIM= 100.0,
 VWALK= 4.0,
 $END
WWET-SLIPRY
Wet-wet,Slippery,June
 $SCENAR
 !MAPG=2,
 LAC=l,
 ISEASN=4,
```

```
ISNOW= 0,
ISAND= 0,
ISURF= 2,
NOPP= 1,
NSLIP= 1,
MONTH= 6,
  COEFHD= 1 .O,
  GAMMA=. 10,
  ZSNOW= 10.0,
RDFOG= 1 OOO.,
REACT=.75,
DCLMAX=2.0,
SFTYPC=90.0,
VBRAKE= 2.0,
VISMNV= 2.0,
VLIM= 100.0,
VWALK= 4.0,
$END
SNOW
Dry,Snow(old),January
$SCENAR
! MAPG=2,
LAC=1,
ISEASN= 1,
ISMODL= 1,
ISNOW= 1,
ISAND= 0,
ISURF= 3,
NOPP= 1,
NSLIP= 0,
MONTH= 1,
COEFHD= 1 .O,
  GAMMA=. 10,
  ZSNOW=lO.O,
RDFOG=1000.,
REACT=.75,
DCLMAX=2.0,
SFTYPC=90.0,
VBRAKE= 2.0,
VISMNV= 2.0,
VLIM= 100.0,
VWALK= 4.0,
$END
SNOW/ICE
Snow(old),ISURF=ICE,Soil=Dry,Visib=January
$SCENAR
!MAPG=2,
LAC= 1,
ISEASN=l, !(DRY)
MONTH= 1, !(January)
ISAND= 0,
NOPP= 1,
NSLIP= 0,
ISURF= 3, !(iCE)
  ISMODL=1, ISNOW=1, COEFHD=1 .O, GAMMA=. IO, ZSNOW=10.0,
RDFOG=1000., REACT=.75, DCLMAX=2.0,
```

```
SFTYPC=90.0,
VBRAKE= 2.0, VISMNV= 2.0, VLIM= 100.0, VWALK= 4.0,
$END
SNOW/DRY
Snow(old),ISURF=DRY,Soil=Dry,Visib=January
$SCENAR
!MAPG=2,
LAC=l,
ISEASN= 1, ! (DRY)
MONTH= 1, !(January)
ISAND= 0,
NOPP= 1,
NSLIP= 0,
ISURF=1, !(DRY)
 ISMODL=1,ISNOW= 1, COEFHD=l .O, GAMMA=.1 0, ZSNOW=10.0,
RDFOG=1000., REACT=.75, DCLMAX=2.0,
SFTYPC=90.0,
VBRAKE= 2.0, VISMNV= 2.0, VLIM= 100.0, VWALK= 4.0,
$END
CRRELSNOW
Dry,Snow,January (new CRREL model)
$SCENAR
!MAPG=2,
LAC=1,
ISEASN= 1,
ISNOW= 1,
ISMODL=2,
ISAND= 0,
ISURF= 3,
NOPP= 1,
NSLIP= 0,
MONTH= 1,
 COEFHD=1 .O,
 GAMMA=. 10,
 ZSNOW=10.0,
RDFOG= 1 OOO.,
REACT=.75,
DCLMAX=2.0,
SFTYPC=90.0,
VBRAKE= 2.0,
VISMNV= 2.0,
VLIM= 100.0,
VWALK= 4.0,
$END
CRREL'ICE
Snow(CRREL),SURF=ICE,SOIL=DRY,VISB=January
$SCENAR
!MAPG=2,
LAC=1,
ISEASN=1,! (DRY)
ISNOW= 1, !(Yes)
ISMODL=2, !(CRREL)
ISAND= 0,
ISURF= 3, !(ICE)
NOPP= 1,
NSLIP= 0,
```

```
 MONTH= 1, ! (January)
   COEFHD= 1 .O,
  GAMMA=. 10,
   ZSNOW=lO.O,
 RDFOG= 1 OOO.,
 REACT=.75,
 DCLMAX=2.0,
 SFTYPC=90.0,
 VBRAKE= 2.0,
 VISMNV= 2.0,
 VLIM= 100.0,
 VWALK= 4.0,
 $END
CRREL/DRY
Snow(CRREL),SURF=DRY,SOIL=DRY,VISB=January
 $SCENAR
 !MAPG=2,
 LAC=1,
 ISEASN=l, !(DRY)
 ISNOW= 1, !(Yes)
 ISMODL=2, !(CRREL)
 ISAND= 0,
 ISURF= 1, ! (DRY)
 NOPP= 1,
 NSLIP= 0,
 MONTH= 1, !(January)
   COEFHD= 1 .O,
  GAMMA=. 10,
   ZSNOW=10.0,
 RDFOG=1000.,
 REACT=.75,
 DCLMAX=2.0,
 SFTYPC=90.0,
 VBRAKE= 2.0,
 VISMNV= 2.0,
 VLIM= 100.0,
 VWALK= 4.0,
 $END
SAND
Dry,Sand,January
 $SCENAR
 !MAPG=2,
 LAC=1,
 ISEASN= 1,
 ISNOW= 0,
 ISAND= 1,
 ISURF= 1,
 NSLIP= 0,
 MONTH= 1,
   COEFHD= 1 .O,
  GAMMA=. 10,
   ZSNOW=10.0,
 RDFOG=1 OOO.,
 REACT=.75,
 DCLMAX=2.0,
 SFTYPC=90.0,
```

```
VBRAKE= 2.0,
VISMNV= 2.0,
VLIM= 100.0,
VWALK= 4.0,
$END
WET-SLIPRO
Wet,Slippery,October
$SCENAR
MAPG=2,
LAC=1,
ISEASN=3,
ISNOW= 0,
ISAND= 0,
ISURF= 2,
NOPP= 0,
NSLIP= 1,
MONTH=10,
COEFHD= 1 .0,
GAMMA=. 10,
ZSNOW=10.0,
RDFOG=1000.,
REACT=.75,
DCLMAX=2.0,
SFTYPC=90.0,
VBRAKE= 2.0,
VISMNV= 2.0,
VLIM= 100.0,
VWALK= 4.0,
$END
```

A.6 NRMM XUV3 vs HMMWV Results

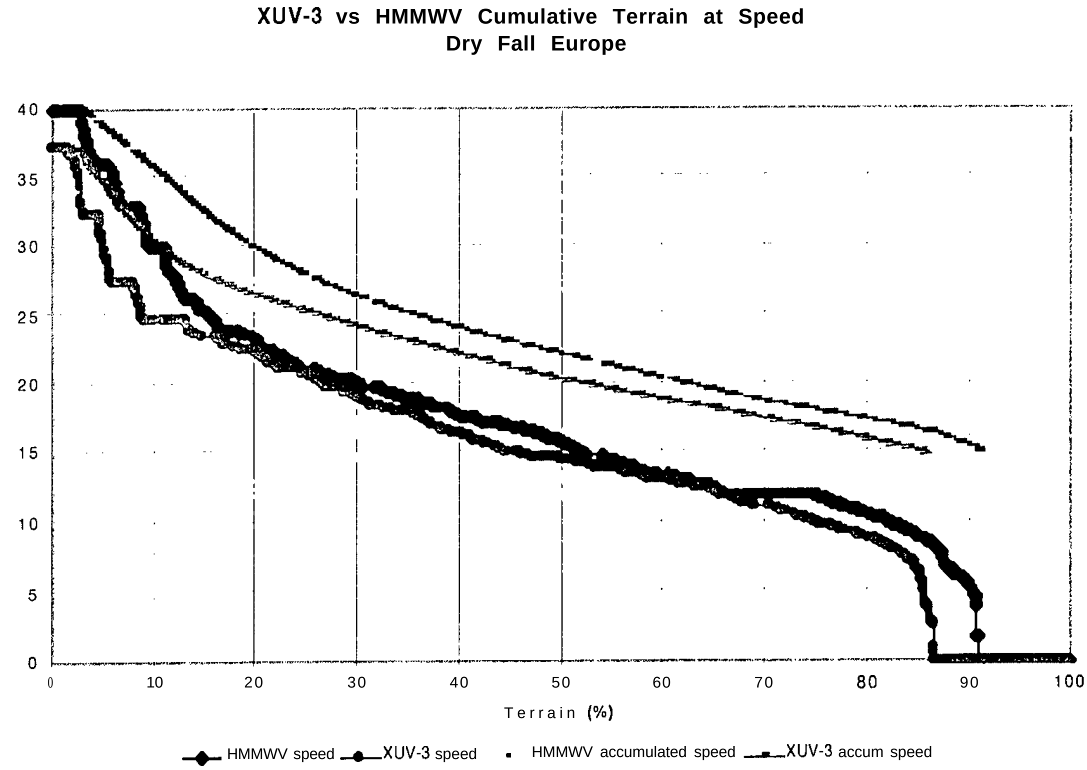

Figure A-l. Comparison of Velocity Profiles for Dry/Fall Europe

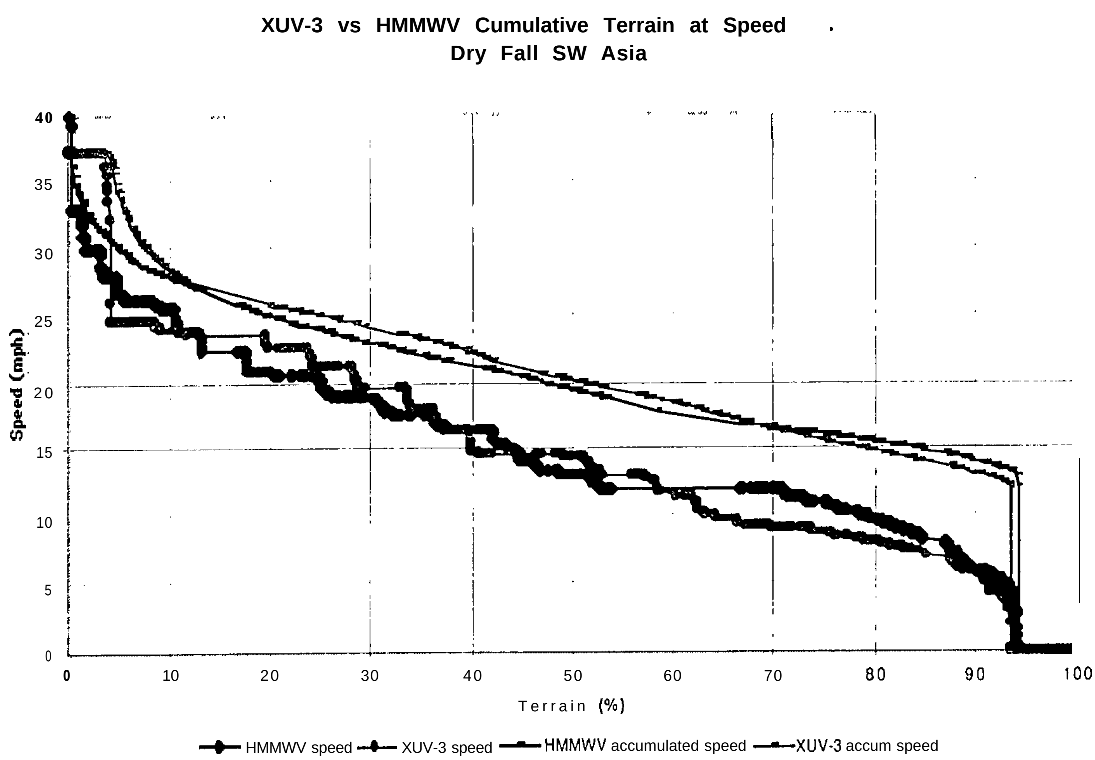

Figure A-2. Comparison of Velocity Profiles for Dry/Fall SW Asia

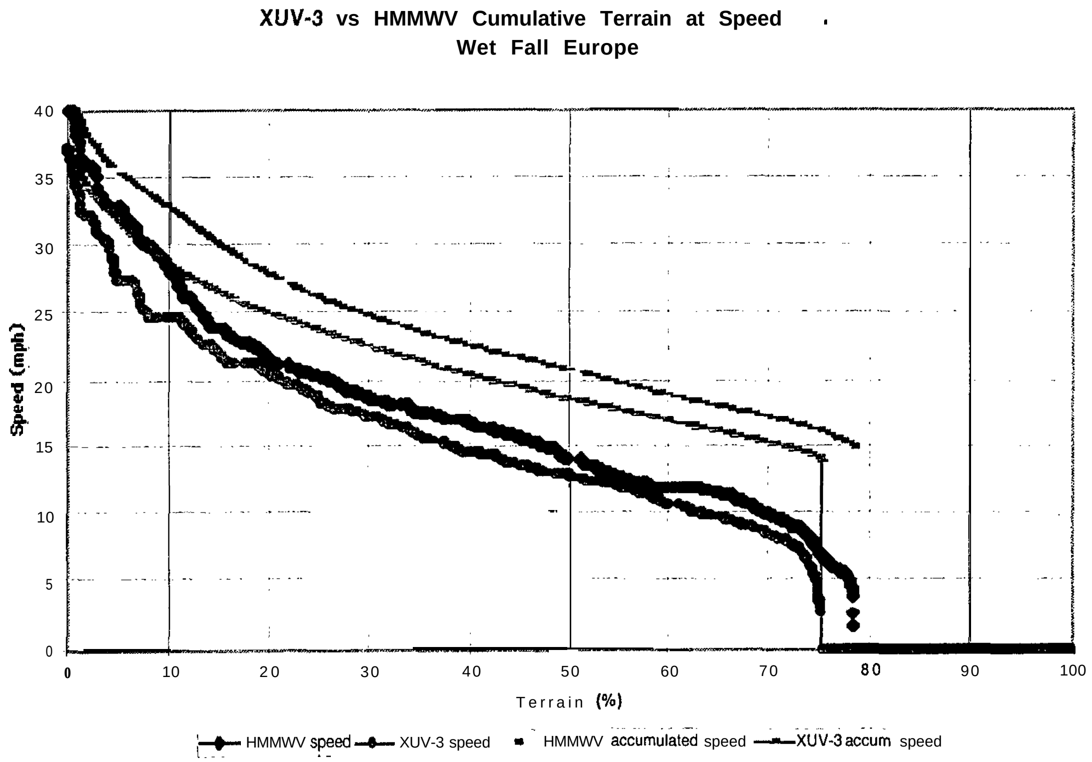

Figure A-3. Comparison of Velocity Profiles for Wet/Fall Europe

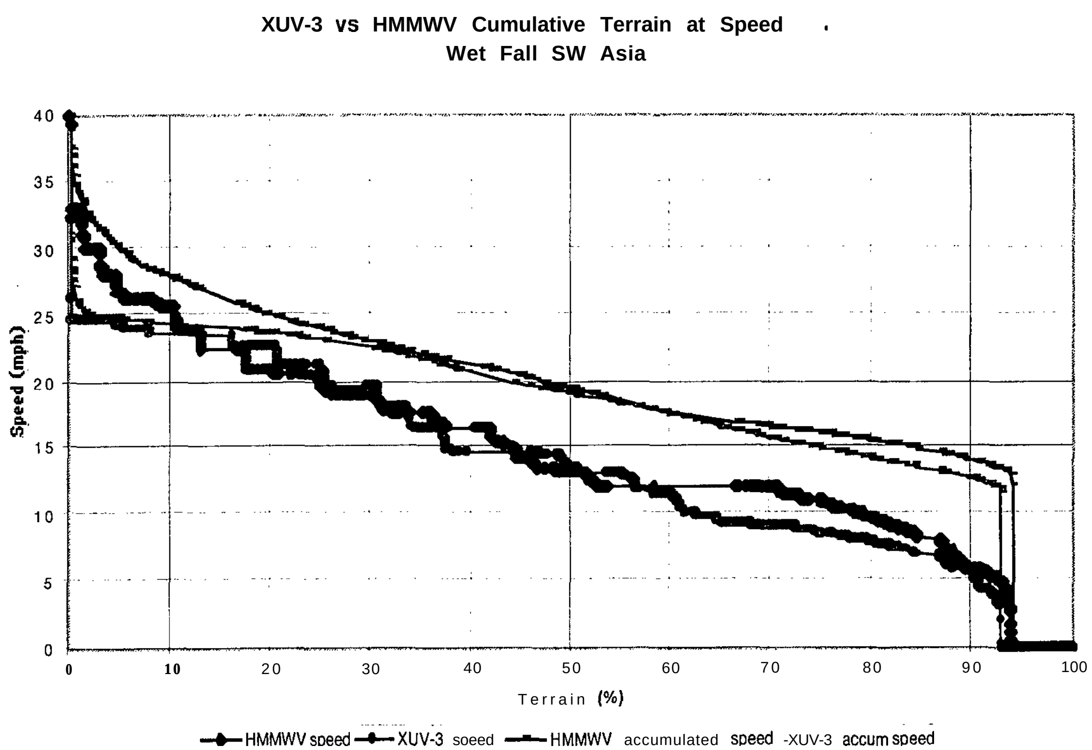

Figure A-4. Comparison of Velocity Profiles for Wet/Fall SW Asia

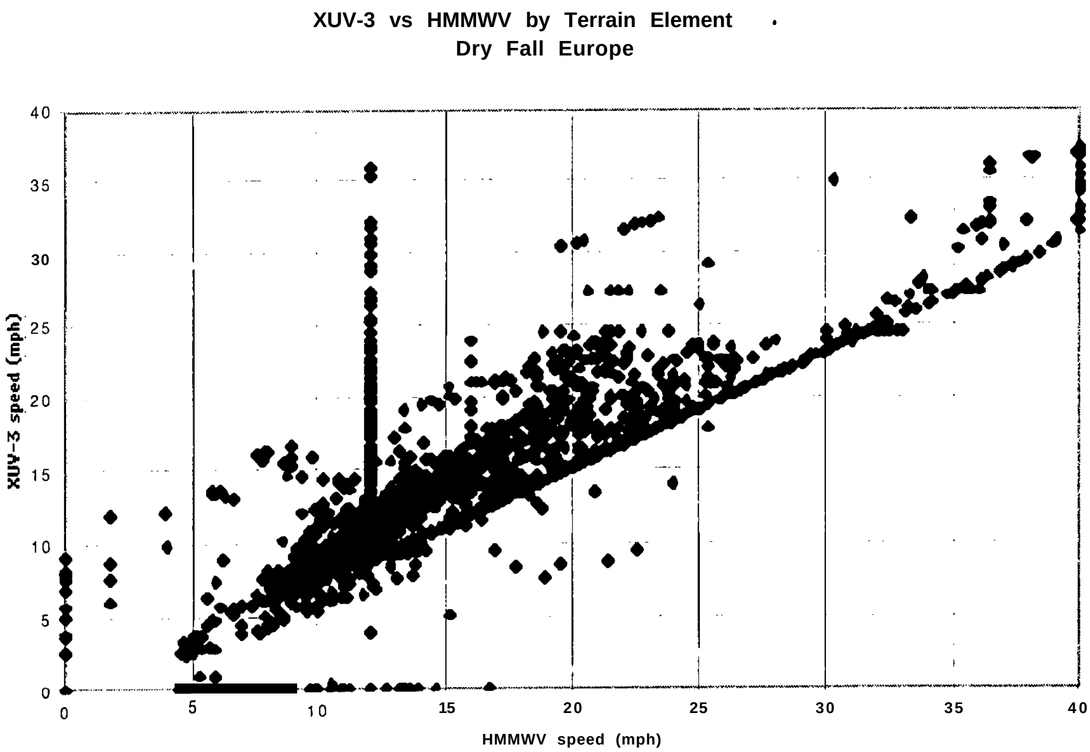

Figure A-5. Scatter Plot by Terrain Element for Dry/Fall Europe

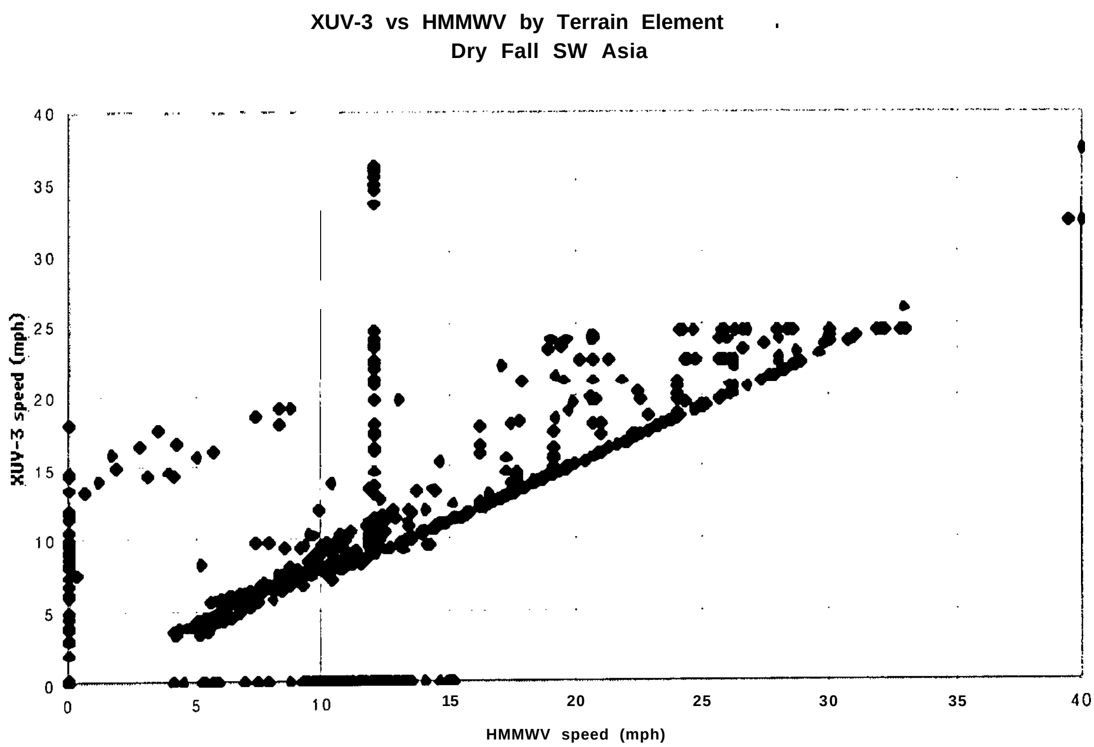

Figure A-6. Scatter Plot by Terrain Element for Dry/Fall SW Asia

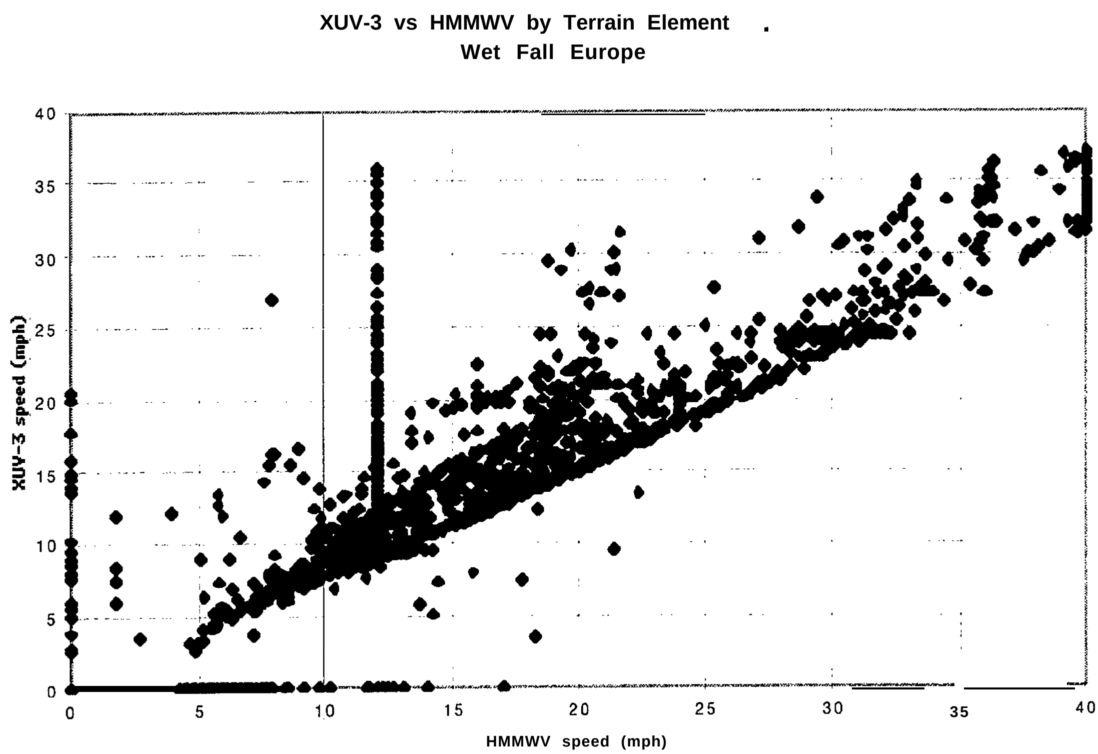

Figure A-7. Scatter Plot by Terrain Element for Wet/Fall Europe

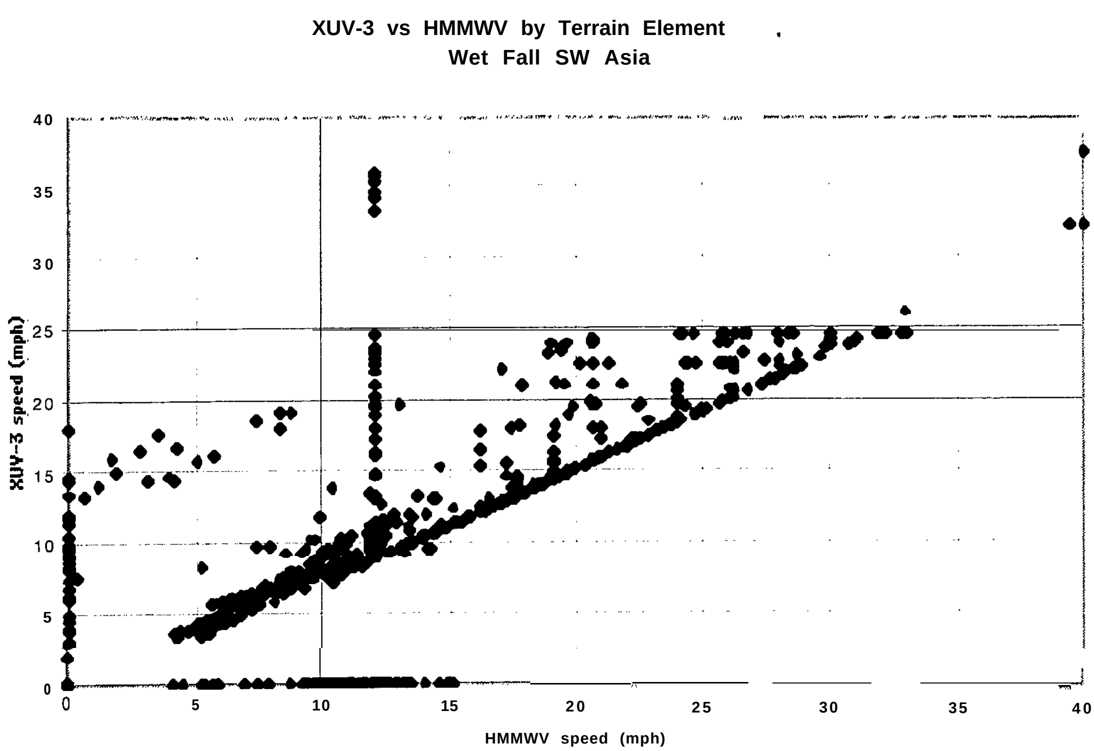

Figure A-8. Scatter Plot by Terrain Element for Wet/Fall SW Asia

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Appendix B:

Vehicle Dynamics II (VEHDYN II) Module

B.l Vehicle Data Input File: XUV3.vd2

```
!vehicle data file for vehdynII
xuv3
DEMO III XUV Robotic Vehicle (7/06/98)
!Date modified: 12 August 1998
!Data from Jeff Robertson (RST) Rev.3, 7/27/98 and hand calculations
1,2,2,0,0
6,0,0.,0.,0.,0.,0.0,10.0        ! front spring
-31.25,0.0,3.0,10.0,10.5,11.0        !front spring displacement (in)
-2500.0,0.0,511.0,1534.0,1709.0,30000.0!force(lb) for front displacement
6,0,0.,0.,0.,0.,0.0,10.0        !rear spring
-31.25,0.0,3.0,10.0,10.5,11.O        !rear spring displacement (in)
-2500.0,0.0,579.0,1736.0,1911.0,30000.0!force(lb) rear displacement
12,0,0.,0.,0.,0.        !front shocks(damper)
-564.,-66.,-65.,0.,65.,66.,69.,73.,84.,110.,190.,564.        !front shock velocity (in/sec)
-196.,-196.,-98.,0.,98.,196.,293.,391.,489.,587.,782.,782. !f shock force for vel.(lb)
12,0,0.,0.,0.,0.        ! rear shocks(damper)
-564.,-66.,-65.,0.,65.,66.,69.,73.,84.,110.,190.,564.        !rear shock velocity (in/sec)
-297.,-297.,-149.,0.,149.,297.,446.,594.,743.,891.,1188.,1188.!rear force for vel. (lb)
0,0,0,2,0,1
26.1,45.0        !driver seat coordinates for absorbed power (2/3 distance from cg at top)
2500, 7263        !weight(lbs),pitch(lb.s^2-in) hand calculation
0,30.0,57.5,45.0,-53.5,15.0!zero load c.g. of veh. wrt ground
14.5,80.0,39.0,13.837,0.663,591.0,1 !front tire, Dunlop Mud Rover at 25 psi
14.5,80.0,-35.0,13.795,0.705,659.0,1  !rear tire, Dunlop Mud Rover at 25 psi
1,1,1,0,0        !front
2,2,2,0,0        ! rear
```

B.2 Sample Control Input File: XUV3_vd2.dat

```
!control file for vehdynII
demoxuv3
4INHR
5.,0.002,-50.48,0.,50.,0.2,0.05
0.1,30.,0
1,1
```

B.3 Tire Load vs. Deflection Data at 25 psi

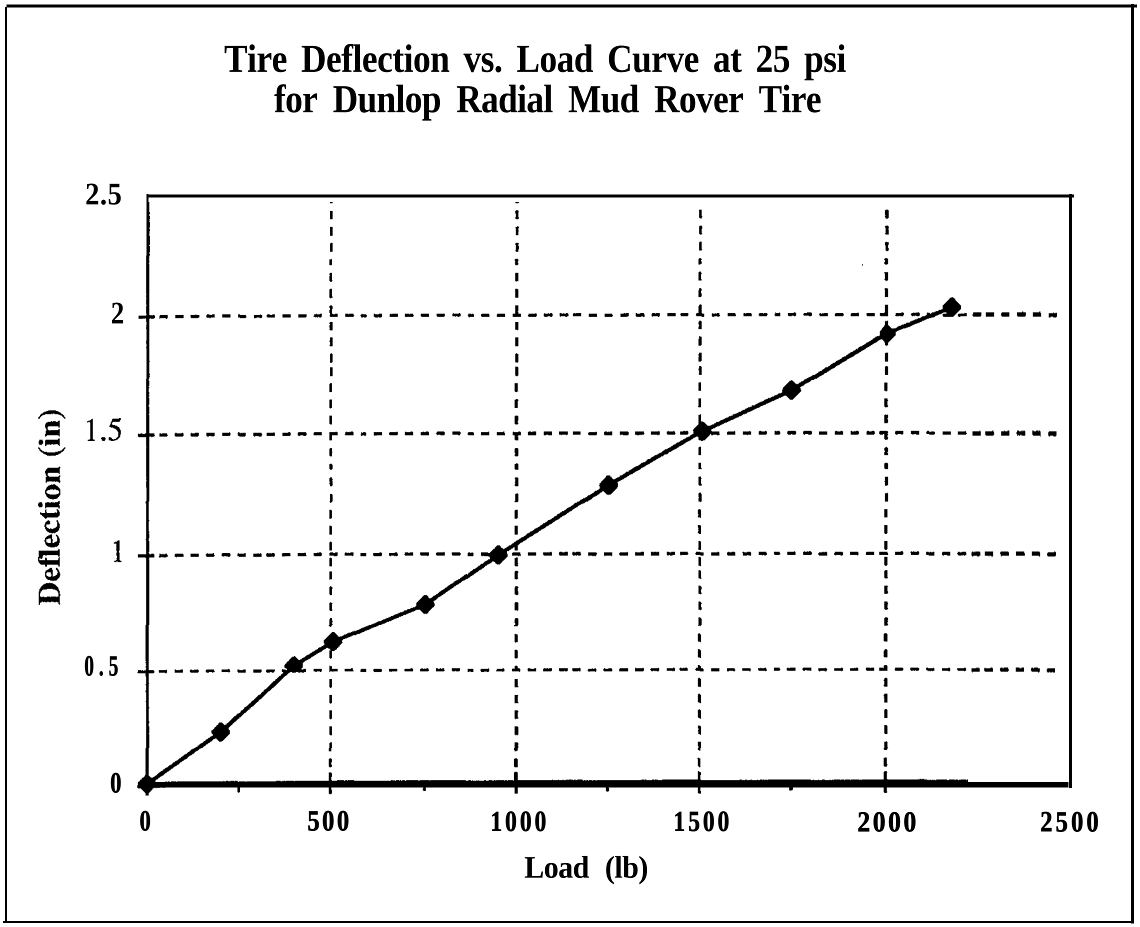

Figure B-l. Tire Deflection vs Load Curve

B.4 Zero-Force Configuration for DEMO III XUV3 at 25 psi

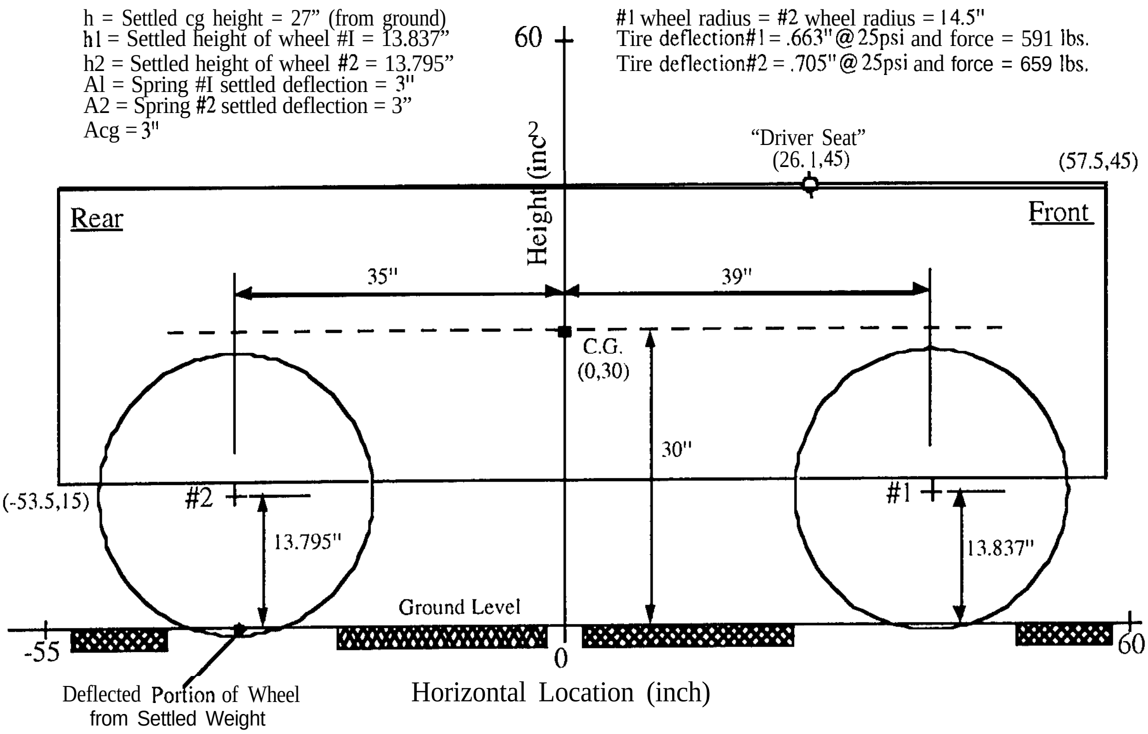

Figure B-2. XUV3 Zero-Force Configuration

Appendix C:

Obstacle-Crossing Module

C.l Vehicle Data Input File: XUV3.veh

```
XUV3, DEMO III UGV (Robotic Systems Technology Inc)
 Project: DEMO III XUV Ver. 3, same # as Jeff Robertson chassis info dated 7/27/98
 Date entered: 08 August 1998
! Date modified: 20 August 1998
 Description:
 OBSMOD DATA from Timothy Vong
XUV3, DEMO III UGV (Robotic Systems Technology Inc)
 $VEHICL
  RB.vong ARL/WMRD 20Aug98
  NUNITS =  1 ! Number of units
  NSUSP = 2! Number of suspension supports
  NVEH 1 =  1 ! Vehicle type; O=tracked, 1 =wheeled
  NFL = O! Track type; 0=rigid,1=flexible
  REFHT1 = 12.0! Height of hitch from ground
  HTCHFZ =   O! V-force on hitch
  SFLAG( 1) = 0,0 ! Type suspenzion  @ supt-i, O=indp, 1 =bogie
  Power flags ((IP(i,j), i=1,nsusp) j=1,2)
  IP(1,1) = 1,1
  Brake flags ((IB(i,j), i=1,nsusp) j=1,2)
  IB(1,1) = 1,1
  EFFRAD(1)= 13.837,13.795  !Effective loaded radius of wheels(hybrid from vehdyn)
  ELL(l) = 92.5, 18.5    !Horiz. pos. suspension WRT hitch
  BWIDTH(1)=   0, 0       !Bogie arm length (wheel to wheel)
  BALMU( 1) =   0, 0      !Bogie max CCW. angl, (+=CCW.) 15"Jounce,6"rebound
  BALMD(l) = 0, 0         !Bogie max CW. angl, (+=CCW.)
  EQUILF(1)= 1182,1318      !Equilibrium force
  CGZ1   =  27.0 ! V-cg, Unit-l wrt ground (from RST)
  CGZ2   =    0 ! V-cg, Unit-2 wrt ground
  DEE1   =   0 ! H-cg, Unit-l payload wrt hitch (not including pan/tilt)
  ZEE1   =   0 ! V-cg, Unit-l payload wrt ground (not including pan/tilt)
  DEE2   =    0 ! H-cg, Unit-2 payload wrt hitch
  ZEE2   =    0 ! V-cg, Unit-2 payload wrt ground
  DELTW1  =    0 ! Payload weight, Unit-l
  DELTW2  =    0 ! Payload weight, Unit-2
  NPTSC1  =     5 ! #Pts, bottom profile, Unit-l
  XCLC l(1) = 111 .O 92.5 53.5 18.5 0.00 ! X, Bottom profile, Unit- 1
  YCLC1(1) = 12.00 12.00 12.00 12.00 12.00 ! Y, Bottom profile, Unit-l
  NPTSC2  =      ! #Pts, bottom profile, Unit-2
  XCLC2( 1) =,     ! X, Bottom profile, Unit-2
  YCLC2( 1) =,     ! Y, Bottom profile, Unit-2
  SFLAG(4)  =      ! Type suspension front "spridler" (always zero)
  IP(4,1)  =      ! Power flag, front "spridler"
  IB(4,1)  =      ! Brake flag, front "spridler"
  ELL(4)  =      ! H-pos front "spridler" wrt hitch
  ZS(4)   =      ! V-pos front "spridler" wrt ground
  EFFRAD(4)=      ! Effective radius front "spridler"
  SFLAG(5)  =      ! Type suspension rear "spridler" (always zero)
  IP(5,1)  =      ! Power flag, rear "spridler"
  IB(5,1)  =      ! Brake flag, rear "spridler"
  ELL(5)  =      ! H-pos rear "spridler" wrt hitch
  ZS(5)   =      ! V-pos rear "spridler" wrt ground
  EFFRAD(5)=      ! Effective radius rear "spridler"
 $END
```

C.2 Control Input File: XUV3.INP

```
! Comments are O-K
! Date Modified: 08 August 1998
XUV3.VEH    ! Vehicle input file, ver # same as Jeff Robertson susp. char. version 3
WHEELS.OBS         ! Terrain input file
XUV3.OUT    ! Summary output file (This file is appended to the end of
!                       the NRMM II main module vehicle input data file.)
nul:              ! "plot" output (not currently implemented)
! the following can be the path name of a file with the following data
! or the data itself
 $SCENAR
  DETAIL  =  1,
  FMU       = 0.95, 0.95, 0.95,
  RTOW      = 0.0, 0.0, 0.0,
 $END
```

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The Advanced Weapons Concepts Branch, Army Research Laboratory (ARL), was asked to assess and evaluate the predicted cross-country performance of the current DEMO III Experimental Umnanned Ground Vehicle (XUV) chassis design using the NATO Reference Mobility Model (NRMM) by the Program Manager of the Department of Defense sponsored DEMO III XUV Program. The XUV modeled approximately 2,500 lb that will be able to traverse cross-country terrain at 20 mph. The XUV is designed to be driven by an autonomous mobility package, but the NRMM does not support autonomous mobility; so, for the purposes of this study, the chassis was modeled as a manned vehicle. Currently, the XUV is in the final chassis and suspension development phase by the systems integrator, Robotic Systems Technology, Inc. The NRMM is a computer-based simulation tool that can predict a vehicle's steady-state operating capability (effective maximum speed) over specified terrain. The NRMM can perform on-road and cross-country prediction of a vehicle's effective maximum speed. The NRMM is a matured technology that was developed and proven by the Waterways Experiment Station (WES) and the Tank-automotive and Armaments Command (TACOM) over several decades. The NRMM has been revised and updated throughout the years; the current version used to perform this analysis is version 2, also known as NRMM II. ARL was also asked to compare the predicted performance of the XUV chassis against the high-mobility, multipurpose, wheeled vehicle (HMMWV) using NRMM II. This report details the NRMM II analysis and assessment of the DEMO III XW and WES HMMWV.

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